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ABSTRACT

Technological alternatives in the evolution of present cable television systems into broadband communication networks (BCN) were assessed. Cost estimates were made for alternatives, and the impact of alternatives on BCN development was investigated. An historical study of cable television technology was made which related it to other communications technologies. A possible path for the evolution of cable television systems into BCN was developed. Alternative distribution systems, terminals, new systems, and technologies were assessed. Economic and regulatory factors were reviewed, and the impact of BCN development on society was predicted, focusing particularly on education. A detailed estimate was made to show how demand for interactive services could affect the design of BCN. The background and alternative policies for issues analyzed in the study were summarized. (CH)

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Final Summary Report

IMPACT OF FUTURE CABLE TELEVISION TECHNOLOGY

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GLOSSARY

1. INTRODUCTION

One purpose of this introduction is to locate our work within the framework of technology assessment. This requires a discussion of both Technology Assessment as a field and the scope and strategy of our study. The major themes of our study are then reviewed, providing an overview of the remaining contents of this report.

The National Academy of Engineering's report "A Study of Technology Assessment"[1-1] defined two classes of technology assessments: problem-initiated and technology-initiated. "While the problem-initiated assessment focuses on solving a stated problem, the process involved in an assessment of a new technology is better represented by analogy with an inverted funnel. The assessment process begins with the new technology at the small end and emerges as a complex pattern of consequences at the large end. As cause-effect chains diverge, predictability of events diminishes". In general, they found that because of the proliferation of impacts, groups made greater progress by converting technology-initiated assessments to problem-initiated assessments. We agree.

We found that two factors limited the scope of the study our budget would allow. In the first place, there is a high and growing overlap between new communication technologies. The viability of a particular technology depends greatly on its competition or combination with alternative technologies. For example, although we were not engaged in a study of computer networks, it became clear that future developments in cable television were strongly tied to their integration with computers. On the one hand, cable television networks appeared to be attractive alternatives to the telephone network for inter-computer data transmission. On the other hand, computers needed to be incorporated in cable television networks to develop individualized, interactive services. Thus, in many cases it would be more fruitful to study the impact of communications technology as a whole on a particular issue, e.g., privacy. The same problems must be addressed in the technological invasion of privacy whether one considers telephone, videophone, cable television, facsimile, or computer technology.

The second and more fundamental factor is science's present state of uncertainty regarding the role of communications in the fabric of society. For example, although several studies have been conducted, there is still little understanding of the effect of television on the social development of children. This lack of understanding makes it particularly difficult to assess the impact of changes in communications technology on society. It is certainly more uncertain than assessing the impact of changes in automobile power plants on pollution.[1-2]

Because of these two factors, we have generally limited ourselves to a problem-oriented study. We have studied technological alternatives in the evolution of present cable television systems into broadband communication networks (BCN). Thus, we have focused our attention on technological alternatives which are likely to raise the cost or lower the capability of BCNs. To be sure, this assumes that the development of BCNs is desirable. (In this respect, our position is similar to that of the authors of "Energy Under the Oceans - A Technology Assessment of Outer Continental Shelf (OCS) Oil and Gas Operations" who set out "to find ways to correct deficiencies and improve OCS oil and gas operations."[1-3]) In any event, the information this report supplies could be used to inhibit as well as encourage BCN development.

The "Energy Under the Oceans" report based their assessment on the conclusion "that the physical technology systems in use in the late 1980's would be substantially the same as those in use today."[1-4] This is unlikely to be the case in telecommunications technology where many technological alternatives already exist or could be developed. The principal focus of our study was to define these technological alternatives, estimate their costs, and determine their impact upon BCN development. Chapter 2 describes cable television technology and relates it to other communications technologies. A possible path for the evolution of cable television systems into BCNs is described in Section 2.3. Alternative distribution systems and terminals are considered in Sections 2.4 and 2.5. New systems and technologies are considered in Sections 2.6 through 2.8. In several instances, our conclusions are based on original technical analyses conducted as a part of this project. Economic and regulatory factors are reviewed in Chapter 3.

Chapter 4 surveys the impact of BCN development on society. Because of budgetary constraints, only the impact of BCN development on education was analyzed in detail. (This analysis has been published separately in a special issue on Social Implications of Telecommunications of the IEEE Transactions on Communications.)

Chapter 5 presents a detailed estimate of how a growing demand for interactive services could affect the design of broadband communication networks. This is an original analysis completed under this project. It translates Baran's estimates of the prospective demand for interactive services into BCN bandwidth requirements. (It has been presented at the 1975 National Telecommunications Conference, NTC 75.)

Finally, Chapter 6 summarizes issues analyzed in this report. A summary of the background and trends for each issue is followed by a discussion of present and alternative policies. Several issues are indicated on which further study is recommended.

REFERENCES

1-1. "A Study of Technology Assessment," Report of the Committee on Public Engineering Policy, National Academy of Engineering, Committee on Science and Astronautics, U.S. House of Representatives, July 1969.

1-2. D. G. Harvey and W. R. Menchen, "The Automobile - Energy and Environment, A Technology Assessment of Advanced Automotive Propulsion Systems," Hittman Associates, Inc., Columbia, Maryland, March 1974.

1-3. D. E. Karsh, et al. "Energy Under the Oceans - A Technology Assessment of Outer Continental Shelf Oil and Gas Operations," University of Oklahoma Press, Norman, Oklahoma 1973, p. 19.

1-4. Op. Cit., p. 17.

1-5. P. Baran, "Potential Market Demand for Two-Way Information Services to the Home, 1970-1990," Institute for the Future, Report R-26, December 1971.

2. CABLE TELEVISION TECHNOLOGY

2.1 Overview

Present day cable television systems have evolved from CATV or Community Antenna Television systems which were installed to provide better television reception in areas where broadcast television reception was poor. This included cities such as Vancouver as well as remote, sparsely settled regions where CATV provided the only TV available. Since CATV offerings were restricted to what was available over broadcast television, relatively few channels sufficed. The CATV operator was paid a monthly subscription for detecting and distributing already existing broadcast signals.

In 1972[2-1] there were 3000 operating cable television systems. The average system had 2500 subscribers and carried 9 channels of video on a cable with 12 channel capacity. The 30 largest cable systems range in size from 19 to 53 thousand subscribers with an average of 26 thousand subscribers. The average ratio of channels carried to channel capacity is 12.5/14.3. (This excludes the San Jose system which apparently carries 24 video channels with a 42 channel capacity. The next largest number of channels was carried by Teleprompter in Upper Manhattan, carrying 19 channels in a 24 channel capacity system.)[2-1]

This chapter considers the present state and future alternatives for cable television technology. Attention is focussed on technological issues, and on technological alternatives in the evolution of cable television into a broadband communications network or BCN.

We begin in Section 2.2 by comparing cable television with other telecommunications media. This raises the issue of bandwidth, that is, limitations on the services cable television systems can supply resulting from limitations on the range of frequencies different media can transmit. Section 2.3 outlines a sequence of stages by which cable television systems could evolve into the broadband communication network of a "Wired City'.

Section 2.4 considers alternative systems for distributing broadband telecommunication services. "Bandwidth" is the basic resource which telecommunication systems supply, just as "energy" is the basic resource which natural gas pipelines and electric power lines supply. Different types of distribution systems have different limits on the amount of bandwidth or range of signals they can supply to different subscribers. We regard these limits and the effective use of the available bandwidth within these limits as the underlying technological issues which must be addressed in an assessment of cable television technology. Because "bandwidth" is a more abstract concept than energy, considerable discussion is needed to clarify these issues and understand their technological implications. Particular attention is paid to space division multiplexed distribution (SDM) systems because they represent a radical alternative to the present trends in cable television system development in the United States. Section 2.4.4 describes a study we have made of how SDM technology could be extended to create a BCN.

One set of implications is discussed in Section 2.5 which considers (a) the bandwidths required by different techniques for displaying information and (b) the extent to which bandwidth limitations can be overcome by modifying subscriber terminals. Section 2.6 summarizes a study we made in this project of alternative techniques for more effectively utilizing available bandwidth to provide individualized subscriber services.

Section 2.7 describes two emerging technologies, optical fibers and facsimile, and the effect they could have on future distribution systems and terminals. Section 2.8 considers the issues raised by the interconnection of cable television systems into regional and national networks.

2.2 Comparison with Broadcast Television, Telephone and Computer Networks

It is instructive to compare cable television with other telecommunications systems. In general, broadcast television and telephone systems serve distinct markets because they provide different services. Historically, CATV systems evolved as alternatives to broadcast television. However, any cable television system has the potential of becoming a broadband communications network or BCN by serving as a common carrier. As a common carrier it would be in direct competition with the telephone system. This is particularly true in the field of digital data transmission where cable television could offer an attractive alternative to the telephone system in forming local computer networks.

Table 2.1 summarizes the technical characteristics of broadcast television, cable television, and the telephone system. The first characteristic to note is the greater range of frequencies (bandwidth) associated with a video channel - 6 MHz as compared with 3 KHz.* Broadcast and conventional cable television are Frequency Division Multiplexed (FDM). That is, many subscribers are connected to the same cable, but the cable carries several channels and each channel occupies a separate frequency band. The subscriber tunes his terminal (receiver) to different frequencies to receive different channels. In contrast, most local telephone systems are Space Division Multiplexed (SDM). That is, each subscriber's telephone handset is connected by an individual cable to a central exchange where any pair of subscriber cables can be connected. In an SDM system each cable carries only one channel; thus narrower bandwidth, lower cost cables can be used.

---

*It is amusing that the ratio of bandwidths for video and audio channels is 2000, in rough agreement with the old adage that one picture is worth a thousand words.

Table 2.1 TECHNICAL COMPARISON OF TELECOMMUNICATION SYSTEMS

	Broadcast TV	Cable TV (1970)	Telephone
Channel Bandwidth	6 MHz	6 MHz	3 KHz
Multiplexing Scheme	FDM	FDM	SDM
Number of Channels	12 VHF	12	= No. of Subscribers
Interaction with Subscribers	1 Way Broadcast	1 Way Cablecast	2 Way Point-to-Point
Transmission Medium	Atmosphere	Coaxial Cable	Two Wire Cable

This difference in multiplexing schemes has a radical effect on the number of channels each system can accommodate. In an FDM system the number of channels is limited by the bandwidth of the transmission medium. If the coaxial cable in a conventional cable television system is connected to an ordinary VHF television receiver, the subscriber is limited to about 12 channels. On the other hand, an SDM system like the telephone network, connects each subscriber to a number of channels equal to the number of names in a telephone directory. More details on multiplexing schemes will be provided in Section 2.4.

The important Technical Issue is the restriction on the number of channels imposed by particular multiplexing schemes. Since each subscriber service requires a channel, restricting the number of channels restricts the number of subscriber services. If particular services do not require the full video bandwidth, this restriction is eased. In any event, the tradeoff between available bandwidth and the demand for subscriber services will be a major theme of this study.

Returning to Table 2.1 we note that both broadcast and conventional cable television are one-way mass distribution services in which each subscriber selects from a set of programs distributed to all subscribers. Cable television has the potential for being less of a mass medium than broadcast television because the number of viewers is restricted by technical restrictions on the length of the cable distribution system. Thus, a typical cable system may have 10,000 subscribers. This is about two orders of magnitude less than the number of viewers for a metropolitan television broadcaster. The social impact of this difference will be considered in Chapter 4 of this study.

The telephone system, in contrast, is a highly individualized and interactive system. Since it allows the individualized connection of any two subscribers, we refer to it as point-to-point service. Conventional cable television more nearly resembles party-line service where anyone on the line can listen in. Since signals can be sent equally well in both directions, the telephone system provides symmetrical two-way service. Cable television systems generally provide asymmetric two-way transmission for interactive services. That is, the return or upstream bandwidth available to the subscriber is very much less than the downstream bandwidth. This is another consequence of bandwidth limitations. It will be discussed further in Section 2.4.

Finally, the potential relationship of cable television to computer networks needs consideration. This is a two-fold relationship. On the one hand, the coaxial cable used in conventional cable television can provide wider bandwidth, lower noise channels for digital data transmission than conventional two-wire telephone cable. (Technical details will be considered in Section 2.4.) On the other hand, all of the individualized services proposed for broadband communication networks involve computer addressing to allow delivery of the service to a particular subscriber. Computer processing of subscriber input is required for all interactive services in which the subscriber can access and manipulate a remote data base. Thus, many of the issues considered in an assessment of computer technology apply to cable television as well.

Incorporation of computers and digital data transmission is a key stage in the evolution of a cable television system into a broadband communications network or BCN. This evolution is discussed in the next section.

2.3 The Evolution of Broadband Communication Networks

Several writers have pointed to the transformation of cable television into "America's National Highway of Communications."[2-2] Ralph Lee Smith writes,[2-2]

> "In addition to the telephone and to the radio and television programs now available, there can come into homes and into business places audio, video, and facsimile transmissions that will provide newspapers, mail service, banking and shopping facilities, data from libraries and other storage centers, school curricula and other forms of information too numerous to specify. In short, every home and office will contain a communications center of a breadth and flexibility to influence every aspect of private and community life."

E. B. Parker[2-3] has described five components of an emerging information utility: a mass storage memory, an interactive console, a communication link, a time-shared computer system, and a set of user programs. He feels that cable television is the most appropriate medium for this communications link.

In their study of "Communications Technology for Urban Improvement,"[2-4] the National Academy of Engineering defined a Broadband Communications Network (BCN) as a "network with a capacity for the exchange of large quantities of information in both point-to-point and broadcast modes." This study suggested that modification of the distribution system to allow (1) upstream information flow and (2) computer-programmed signal distribution to selected subscribers were essential stages in the development of BCNs from existing cable television systems.

We have defined cable television technology in terms of a hierarchy of performance levels. These correspond to a plausible sequence for the evolution of a conventional cable television system into a broadband communications network. Our hierarchy is given in Table 2.2, where the classifications proposed by MITRE[2-5] and Rand[2-6] are shown for comparison. We have used existing telecommunications facilities, broadcast television and the telephone network, to define a base line for performance levels. These levels are described below.

Differences in the order of evolution are certainly possible. We have indicated Rand's order of levels in parentheses since this represents a different view of evolutionary order. The MITRE classification involves some confusion between services and the level of technology required to provide those services.

1. Conventional Cablecast

   This corresponds to most present cable television systems as discussed in Sections 2.1 and 2.2.

2. Local Origination

   In 1972 almost half (49%) of the cable systems provided some form of automated program service such as time/weather, news wire, or stock ticker. Only half of these (25%) provided additional facilities for live, taped, or film program origination.[2-1]

3. Terminal Attachments

   Subscription or pay TV services have been implemented by attaching devices to the subscriber's terminal which allow him to receive programs on otherwise restricted channels. The technologically simplest attachment would be a channel blocking filter which can be removed to allow the subscriber continuous viewing of a restricted channel. Installation of a coin-operated descrambler would involve more complex technology and would allow the subscriber to pay for a particular program. More sophisticated attachments which allow the sort of centralized automatic billing provided by the telephone company could be devised if the system provided for data return.

4. Data Return

   Several services can be implemented by devoting some cable bandwidth to the return transmission of data from the subscriber to the headend. Restricting the upstream bandwidth limits the rate of information a subscriber can send. This is advisable since bandwidth is a limited commodity in a cable system. Specific requirements are discussed in Section 2.4.

5. Addressed Message

   For most applications of the above systems (i.e., meter reading) the address of each terminal needs to be stored at the headend to identify the source of the information. Such a system can be extended to allow the transmission of messages to individual terminals by incorporating some provision for call signalling. At lower performance levels, communication is only between the headend and subscriber. This level of performance allows point-to-point two-way communications between subscribers to be relayed through the headend. However, it is useful to note that most of the features we take for granted in the telephone system would now have to be incorporated in the cable television system. That is, the caller would have to request service, be informed that the system was ready, enter the callee's address,

Table 2.2 PERFORMANCE LEVELS OF BROADBAND COMMUNICATION SYSTEMS

RPI	MITRE[2-5]	Rand[2-6]
0. Broadcast Television and Telephone		
1. Conventional Cablecast	Conventional One-Way	
2. Local Origination	Full One-Way	(IA) Additional Channels
3. Terminal Attachments		(IB) Subscription Channels
4. Data Return	Subscriber Response	(IIIA) Interactive Television
	Utility and Maintenance	(IIIB) Sensor Monitoring
		(IVA) Audio Response
5. Addressed Message		(II) One-Way Addressed
6. Processed Message	Electronic Information Handling	(V) Subscriber Initiated
7. Video Return		(IVB) Video Response
8. Point-to-Point Video	Point-to-Point	(VI) Point-to-Point

signal the callee, and learn whether or not the callee was available. (In the telephone system these features correspond to picking up the handset, hearing a dial tone, dialing a number, and listening to ringing on the other end of the line.) Just as in an electronic switching exchange, a computer would be needed to control these functions in a multiple subscriber system.

6. Processed Message

Once a computer is incorporated in the system, it can be shared by the subscribers to perform a multitude of tasks. The sorts of tasks a computer can perform are varied and well enough known to require no elaboration. There are, however, two considerations which particularly affect the incorporation of computers into a cable network. The first is simply to note that a full use of the computer may require a more sophisticated terminal. In particular, some form of video storage or buffer storage plus character generator may be needed. The second is to note that the same bandwidth on a coaxial cable network is far superior to that on a local telephone network for transmission of digital data.

7. Video Return

Video return is possible even on subsplit single cables if only a few subscribers occasionally require its use. If there is much demand for such service, however, the capacities of conventional FDM systems would soon be overwhelmed. This is discussed more quantitatively in Chapter 5. An alternative SDM distribution scheme which is more easily expanded to meet increased demand is discussed in Section 2.4.

8. Point-to-Point

The ultimate broadband cable system would incorporate video return with message addressing and processing to combine the performance capabilities of television, telephone, and time-shared computing systems. Such a system would resemble the videophone in some respects but would have a higher resolution (wider bandwidth) video display. We address the question of interconnecting cable systems to provide long distance communications in Section 2.8.

2.4 Distribution and Multiplexing Schemes

2.4.1 Overview

Broadband cable communication systems can be divided into three technologically distinct modes distinguished by the way they segregate channels: frequency division multiplexed (FDM), time division multiplexed (TDM), and space division multiplexed (SDM). Broadcast television is an example of an FDM system, a time-shared computer is an example of a TDM system, and the telephone network is an example of an SDM system. Since these modes differ principally in their distribution systems, similar headends (common services equipment) and terminals can be used for all modes. The next three sections consider these three technologies in more detail.

2.4.2 Frequency Division Multiplexed Systems

Because of its close connection with broadcast television, cable television technology has closely paralleled broadcast television technology. Frequency assignments for broadcast television are listed in Table 2.3. Each channel is assigned a 6 MHz frequency band with VHF channels between 54 and 216 MHz and UHF channels from 470 to 890 MHz. Of particular interest is the large frequency gap between Channels 6 and 7. Part of this gap (88 to 108 MHz) is occupied by FM broadcasting.

Thus, an ordinary, unmodified VHF television receiver attached directly to a coaxial cable having a 0 to 216 MHz passband can receive all 12 VHF channels. This is the way CATV systems were originally designed. UHF channels were shifted into unused channels in the VHF spectrum by the CATV operator.

This clearly represents an inefficient use of the bandwidth available on the coaxial cable, since only 72 out of 216 MHz are used for television transmission. This is a utilization efficiency of 72/216 or 1/3. A "mid-

Table 2.3 FREQUENCY ASSIGNMENTS FOR BROADCAST TELEVISION

	Channel Numbers	Assigned Frequencies
VHF	2 - 4	54 - 72 MHz
	5 - 6	76 - 88
	7 - 13	174 - 216
UHF	14 - 83	470 - 890 MHz
FM		88 - 108 MHz

band" from 120 to 174 MHz divided into 9 channels labeled A through H has received general acceptance in the cable television industry. Transmission at these mid-band frequencies allows the subscriber to receive a total of 21 channels, but requires installation of an additional device at each subscriber receiver. This device, known as a converter, shifts the mid-band frequencies into a range which is receivable by a conventional television set. With 300 MHz coaxial cable now becoming available, a "super-band" can be provided with 13 additional channels giving a total of 34 channels available to the subscriber. Note that to receive mid-band frequencies an additional item of terminal equipment is required, but the cable distribution system does not need to be modified. To receive super-band frequencies, older coaxial cable distribution systems would have to be entirely replaced.

Unfortunately, the addition of these extra channels raises problems of interchannel interference that do not arise when only the VHF channels are transmitted. (In fact, avoidance of interchannel interference was one of the factors in the original assignment of VHF channel frequencies by the

FCC.) These problems are discussed in detail by Ward[2-7] in Appendix A of his report and reviewed by Jurgen.[2-8] To surmount these problems, appropriate precautions have to be taken in the design of subscriber equipment and the allocation of channel frequencies.

Two-way services are accommodated on an FDM system by assigning a portion of the frequency spectrum to upstream transmission from the subscriber to the headend. Single-cable subsplit and midsplit systems are commercially available with upstream transmission from 5 to 30 MHz and 5 to 108 MHz, respectively.[2-9] Upstream and downstream channels are separated by 12 to 14 MHz to minimize interference.

In present FDM systems signals from an antenna tower are amplified and may be shifted in frequency at a control center called the "headend." Signals from the headend flow downstream to the subscriber over a tree-like distribution network. This network begins with a limited number of high performance trunk cables which branch into lower-performance feeder cables. "Housedrops" are made by attaching cables from each subscriber home to the feeder cable. Once the feeder cables are installed in a particular neighborhood, additional subscribers can be added to the system by attaching additional subscriber cables (drops) to the feeder cable. To minimize the costs of changing the distribution system the points of attachment (tap points) for all potential subscriber cables are often installed at the same time as the feeder cable. The ratio of actual to potential subscribers is called the penetration and is a key factor in the profitability of a cable system. The layout and performance of a modern cable television system of conventional design is described by Taylor and Janes.[2-10]

Because signals lose strength as they travel along the cable, amplifiers are installed periodically to maintain the strength of the video signals. A lower limit to the signal strength or voltage is set by noise, i. e. random fluctuations of voltage introduced by the transmission medium which mask the signal. An upper limit to the signal strength is set by distortion and interference, i. e. high voltage signals are distorted when amplified and are more likely to interfere with signals on other channels. Since each amplifier adds noise and distortion to the signal, this limits the number of amplifiers on each transmission path. Thus, the total length of a transmission path is limited to about 20 miles by current cable loss and amplifier noise and distortion characteristics. Because cables must be routed circuitously to follow the maze of streets in a community, one headend can only serve subscribers within about a 12 mile radius.[2-11] The design of FDM cable television distribution systems is discussed by several authors.[2-12, 2-13]

Despite these limitations, cable television systems should be far superior to ordinary telephone lines for the transmission of digital signals. Table 2.4 compares telephone and cable television channels on the basis of bandwidth, distortion and signal-to-noise ratio. Although the table is rather technical, the conclusions to be drawn from it can be summarized fairly simply. Note that we are comparing the characteristics of a 4 MHz cable television channel with a 2 KHz telephone channel. Over a 2 KHz bandwidth we would expect about 1000 times less distortion (differential attenuation and delay) and about 15 dB (30 times) better signal-to-noise ratio for the cable television channel. Thus, cable television channels not only provide 2000 times more bandwidth but also provide much better performance in the same bandwidth than telephone channels.

Table 2.4 COMPARISON OF CHANNEL QUALITY

	Telephone[2-14]	Cable TV[2-10]
Bandwidth*	2 KHz	4 MHz
Distortion		
Differential Attenuation	2.5 dB	1 dB
Differential Delay	1 ms	140 ns
Signal-to-Noise Ratio	30 dB	40 dB

2.4.3 Time Division Multiplexed Systems

In many respects, time division multiplexed (TDM) telecommunication systems are intermediate between FDM and SDM systems. TDM systems are related to FDM systems because the information contained in a given message is a product of the bandwidth and the time required to send it. This means that the same amount of information can be sent over a narrow bandwidth channel in a long transmission time or in a short time over a wide bandwidth channel. Channels with the same information capacity can be multiplexed either by slicing the available frequency range into narrow bands (FDM) or by using the full frequency range but slicing the transmission time into narrow intervals (TDM). This is represented graphically in Figure 2.1; equal areas correspond to equal information capacities.

---

*This is the bandwidth effectively available for the transmission of signals. The bandwidths of 3 KHz and 6 MHz previously mentioned for telephone and cable television channels include guard bands to minimize interchannel interference as well as additional bandwidth allocated to modulation and control signals.

TDM systems are related to SDM systems since both involve switching. In TDM systems the signal is switched while in SDM systems the channel (wire or cable) is switched.

The report, "The Wired City: 1980," prepared for the President's Telecommunications Task Force and published in June 1968[2-15] emphasizes TDM systems. It is interesting to note that while this report begins by contrasting TDM and FDM systems it ends by proposing the conversion or supplementation of SDM systems by TDM systems for low and medium bandwidth communications wherever possible. This report and its sources are the basis for our discussion of TDM systems, first in contrast with the previous discussion of FDM systems and then in preparation for the following discussion of SDM systems.

In TDM systems a particular signal only has access to the communication channel for a brief interval, followed by a relatively long period during which other signals are transmitted. Thus, only samples of a continuous signal are transmitted. This can result in serious distortion unless the signal is sampled "often enough." It can be shown that if the signal has a bandwidth W Hz, that 2W samples per second are "often enough" to recover the signal without distortion.

Let us now consider the details of a particular sampling or modulation scheme. In Pulse Code Modulation (PCM) the amplitude of each sample is represented (encoded) as a sequence of binary data bits. It takes about

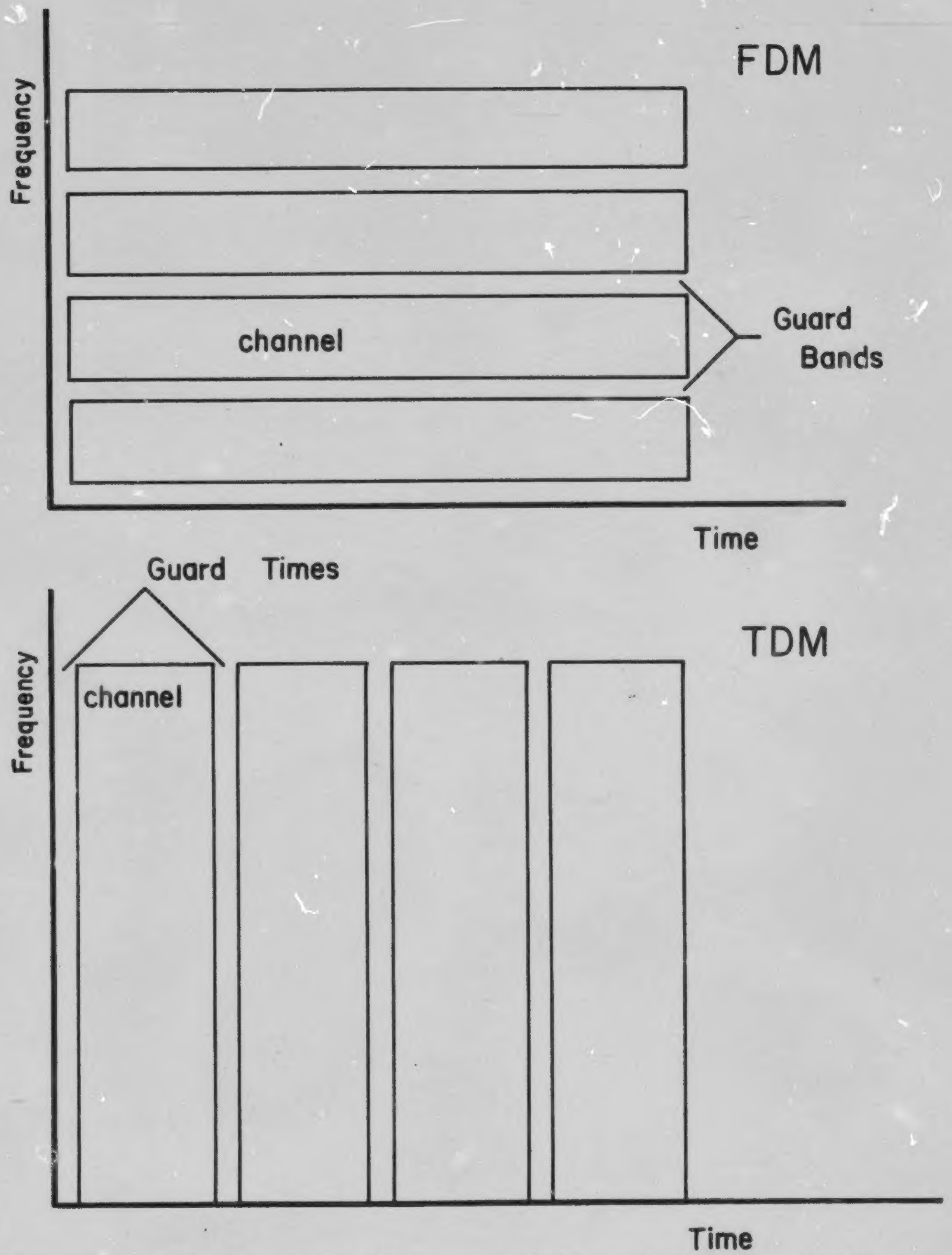
FDM
Frequency
channel
Guard
Bands
Time
Guard Times
TDM
Frequency
channel
Time

Figure 2.1 Comparison of Frequency Division Multiplexing (FDM) and Time Division Multiplexing (TDM)

7 bits per sample to provide good picture quality in television reception. This corresponds to a digital data rate of 7 x 2W = 14W bps (bits per second). The bandwidth required to transmit a digital data rate of 14W bps is about 14W Hz under practical conditions. (The theoretical limit is 7W Hz.) This means that a PCM video signal occupies 14 times the 4 MHz bandwidth of the original video signal. This would restrict the number of available channels in a PCM TDM system to about 1/14 of the number available in a conventional FDM system.

This high bandwidth requirement can be reduced by using a computer to remove redundancy. (One scheme is based on the approximation of an analog waveform by a sequence of straight-line segments lying within a specified percentage of the original waveform. Only the end point amplitudes and time interval are encoded and transmitted in PCM form.) These techniques make it possible to reduce bandwidth requirements 5 times for voice communications and 5 to 8 times for video communications. Such schemes are used to minimize the bandwidth requirements for video telephones whose signals are generally transmitted in digital form. For example, Bell System's Picturephone transmits a lower resolution picture corresponding to a signal with a 1 MHz bandwidth.[2-10] By using the fact that adjacent elements of a black and white television picture are often the same shade of gray, computer processing was able to reduce the data rate for Picturephone transmission to 6.3 Mbps.[2-16] There is a more thorough discussion of the restrictions bandwidth places on video telephone transmission in Reference 2-17.

We conclude that TDM greatly increases the bandwidth requirements for the transmission of signals, but this bandwidth increase can be reduced to some degree by using a computer to process the signal. There is a definite tradeoff between the amount by which the bandwidth can be reduced and the amount (and expense) of computer processing. At this point, the reader may wonder why anyone would want to use a multiplexing scheme having such manifest disadvantages. There are two reasons. In the first place, messages to and from time-shared computers are always in the form of time division multiplexed digital data. Thus, TDM must be incorporated to some degree in any interactive television service.

The second great advantage of TDM is its relative immunity from noise and distortion in comparison with FDM systems. The amplifiers used in FDM systems have no mechanism for separating signal from noise. Digital amplifiers (more accurately described as a regenerative repeaters) can produce clean signals from signals severely degraded by noise. This means that the effects of noise and distortion in one transmission link, if not too great, produce no effect whatever on the regenerated input signal to the next link. Unlike the FDM system discussed in the last section, the noise and distortion from individual links does not accumulate. Since the characteristics of a TDM system only depend on the characteristics of a single link, the length of the system does not matter.[2-18] Unlike FDM systems, TDM systems of arbitrary length can be constructed. Because of this, Kirk and Paolini[2-19] have proposed a digital transmission scheme for the interconnection of local cable television networks.

To be of value, a digital transmission scheme must transmit digital data with minimum error. The probability of error can be related to the signal-to-noise ratio of the data channel. This relationship is shown for pulse code modulation in Table 2.5.

Table 2.5[2-18] PCM ERROR PROBABILITIES FOR GIVEN SIGNAL-TO-NOISE RATIOS

S/N (dB)	13.3	17.4	19.6	21.0	22.0	23.0
Probability of Error	10^{-2}	10^{-4}	10^{-6}	10^{-8}	10^{-10}	10^{-12}

An error probability of 10^{-5} is typical for data transmission at a rate of 2.4 Kbps over ordinary voice-grade telephone lines.[2-20] In Table 2.4 we noted that "flawless" television reception requires a signal-to-noise ratio of 40 dB. From Table 2.5 we see that the signal-to-noise ratios presently available in well-engineered cable television systems allow virtually errorless data transmission by comparison with ordinary telephone lines.

By changing the modulation scheme we can trade this lower probability or error for a higher data rate. Presently, a great deal of research and development is conducted to produce devices which will maximize the rate of data transmission over telephone lines while maintaining acceptable probabilities of error. These devices are called modems. Modems are available which will allow data to be transmitted at rates from 300 to 4800 bps over ordinary, unconditioned direct distance dialing (DDD) lines.[2-21] Digital data can be sent over telephone lines at a rate of 300 bps without using modems.[2-22] Higher data rates require more expensive modems. The higher signal-to-noise ratio of cable television channels would allow data to be transmitted at higher rates by less expensive modems, using the same bandwidth that telephone lines presently provide.

Table 2.6 compares the analog bandwidths and PCM data rates for different classes of signals if no attempt is made to reduce bandwidth by computer processing.

Table 2.6[2-15] APPROXIMATE CHANNEL CAPACITIES FOR DIFFERENT CLASSES OF SIGNALS

Signal Class	Analog Bandwidth	PCM Data Rate
Low (Audio)	4 KHz	50 Kbps
Medium (Videophone)	500 KHz	7 Mbps
High (Television)	4 MHz	50 Mbps

It is interesting to note that high-speed, high-resolution facsimile pictures can be transmitted at low to medium data rates. This is an alternative to video transmission for many interactive services and will be considered in detail in Sections 2.5 and 2.7.

The 50 Mbps rate seems to be a reasonable upper limit for inter-computer communications. Mass data transfer between computer memories would require about 150 ms to transfer 8 Mb of data at a 50 Mbps rate. If two computers were working jointly on a program it might be desirable to have such high speed dialogue between the machines. However, the internal processing rate of today's very fast computers is about 600 Mbps which is close to the limit imposed by the transit time of signals on wires inside the computer. A significant increase in rate requirements would exist, however, if many computers were hooked together in parallel to work on a single problem.

Compared with FDM systems, TDM systems tend to involve simpler circuitry. "FDM requires subcarrier modulators, band pass filters, and demodulators for each message channel; these are replaced by the comutator and distributor of TDM."[2-23] This advantage is likely to increase as integrated circuits reduce the cost of digital circuitry. TDM does require synchronization of commutator and distributor to keep signals in step, but the synchronization requirements are only slightly more complex than they are for FDM with suppressed carrier modulation.[2-23] In addition, TDM systems are ideally suited for digital data processing techniques such as secrecy or security scrambling. In consequence, TDM systems can accommodate variable information rates more easily than FDM systems. This allows the capacity of a cable to be used in proportion to the information rate, so that subscriber prices can be set according to actual information usage. Tradeoffs between TDM and FDM for data communication in Broadband Communication Networks are considered in Section 2.6.

PCM signals are well matched to "guided wave" transmission media such as waveguides and light beams. These media have very wide bandwidth capability, but their transmission characteristics allow appreciable interference between simultaneously transmitted signals. PCM's cross-modulation immunity makes it extremely attractive for the development of these media as communication channels.[2-15] This, of course, is quite pertinent to the use of optical fibers for CATV distribution as discussed in Section 2.7.

We conclude that the bandwidth limitations of coaxial cable and the greater bandwidths required for TDM transmission in comparison with FDM transmissions will limit TDM systems to "long line" applications which require transmission through many repeater stages. It is instructive to consider the telephone network where PCM TDM systems are rapidly replacing SDM systems, beginning with interoffice trunking ($\gtrsim$ 10 miles) and now extending to local exchanges.[2-24] As outlined below, PCM TDM systems offer several advantages over SDM systems.[2-25]

A TDM system requires fewer switches than a purely SDM system. Although this has long been recognized, operation in a PAM (Pulse Amplitude Modulation) mode was not economical because of inter-channel interference (crosstalk), non-uniform signal amplification, and modem requirements. In the PCM mode these difficulties disappear. One expects that the higher noise tolerance of PCM systems will raise the tolerance of reflections from switches and cable discontinuities. This would allow electromechanical relays to be replaced by solid state switches in telephone switching exchanges, making them more compact and economical.

As the above discussion suggests, the intimate integration of time multiplexing with switching means that no clear line of demarcation can be drawn between TDM and SDM systems. In practice, engineering decisions have to be made as to whether TDM or SDM switching is preferable throughout a distribution system. The modulation and demodulation functions of FDM transmission cannot readily be integrated with either TDM or SDM switching.

Since both communication and communication control information can be processed by the same circuitry in a TDM system, extreme flexibility is possible in switching system design. One expects that the possibilities this offers are comparable to those offered by integration of data and instructions in computer programs. For one thing, control and communication signals can be sent sequentially on the same channel.

Since data transmission between digital computers will be an increasing fraction of the traffic on communication channels, one expects that telecommunication systems will need to be designed for efficient communication of digital data. So far, research has concentrated on the transformation of signal waveforms for efficient transmission over existing channels. One area which is beginning to receive attention is the application of traffic theory to optimize the flow of randomly received data on a statistical basis. Rubin[2-26] indicates that the application of traffic theory can raise the efficiency of digital data transmission from 2% to 50% in some cases.

2.4.4 Space Division Multiplexed Systems

Space division multiplexing is a viable alternative to FDM for cable television systems. Although not common in the U. S., such a system has been operating in Great Britain[2-27, 2-28] and has been tested at Dennis Port, Cape Cod, Massachusetts.[2-8] The subscriber can select any of 36 channels using a remote controlled rotary switch. Since each subscriber needs to have his own dedicated channel, they have developed a type of cable known as "6-Quist" which contains 6 channels in a 1/2-inch diameter cable. Each channel consists of two pairs of wires, one with video (0-15 MHz) capabilities and the other with control (0-1 MHz) capabilities. Since conventional television receivers are designed to work in the UHF-VHF region, it is necessary to take signals from the Quist and upconvert them to an appropriate frequency. Rediffusion has also built less expensive television receivers without video detection to be connected to the 6-Quist system without an upconverter.

The evolution of cable television technology has followed a different path in Great Britain than in the United States. FDM cable television technology developed from a desire of television retailers in isolated communities to increase the market for the terminals they were selling. They found that they had to provide signals at cost in order to sell the sets at a profit. As a result, a tendency has developed to minimize the cost of investment in the distribution system and use more expensive terminals to supply a wider range of interactive services. In England two companies (Rediffusion Limited and British Relay Wireless Limited) had built up a substantial business using an SDM system to relay sound programmes by wire to some one million subscribers in urban areas.[2-28] Since part of their revenue came from the rentals of loudspeakers with volume control, television picture tubes with picture controls, and program selection devices they were concerned with minimizing the total cost of the system, including the terminal. "The economics are such that it is less costly to provide sensitive and therefore high-fidelity loudspeakers than to use cheap units that need more copper in the distribution network."

The existence of two competitive, generally incompatible cable television technologies raises a major Technological Issue similar to that involved in choosing new propulsion systems for automobiles.

Although an SDM system tends to be more expensive than an FDM system, it offers the possibility of lower cost expansion to an ultimate BCN with an indefinite number of virtual channels and point-to-point video interconnection. It also offers more complete freedom from multiplexed-channel interference effects than FDM or TDM systems. J. P. Thompson of

Arthur D. Little, Inc., after analyzing both FDM and SDM systems, has suggested that SDM would provide the optimum cable telecommunications system if expanded to allow interactive services.[2-29]

Present SDM cable television systems are more limited than the telephone network. Some of these limitations are:

1. Limited channel capacity. One is limited to 36 channels by the Rediffusion system. In contrast, the number of telephone network channels equals the number of telephone numbers!

2. One way design. Two-way communications requires special bidirectional amplifiers on the cable networks and additional equipment at the distribution centers.

3. Limited two-way communication. Point-to-point two-way communication is not possible unless the distribution center actively engages in transmitting the return communication signals in the outbound spectrum interval.

4. No provision for call signaling. Two-way communication can be initiated only when both participants have prior knowledge of the need for communication. Alternatively, the called terminal must be remotely energized by some form of analog or coded digital signal.

5. No simple billing procedure for special communication services. A toll meter must be installed at the subscriber terminal which may either record accumulated toll time or respond via a narrow-

band return channel to a readout signal from the distribution center. Otherwise, flat-rate tolls must be applied for special services.

In attempting to compare interactive FDM and SDM cable television technology Thompson commented that, to his knowledge, "no definitive technical study has been made as to the number of effective two-way video channels that could be available over a basic SDM system at various times during its ultimate completion, (and) the trunking bandwidth necessary at various times or networking of neighborhood systems." He added that these issues needed to be resolved before one could see any major implementation of such systems.

Since future SDM technology needed to be defined before it could be assessed, we considered the design of a SDM system which provides both cablecast and individual services. Our design is reported in a special issue of the IEEE Transactions on Communications devoted to Interactive Broadband Cable Systems.[2-30]

Cablecast services are the distribution of entertainment and information customarily associated with cable television. These services are usually of interest to a majority of subscribers and are characterized by high traffic rates and long holding times (subscriber interest spans). We assumed that individual services are usually directed to (or requested by) relatively few subscribers. Thus, individual services have low to moderate demand rates with holding times which depend on the particular service required.

Cablecast Services are best transmitted on a cable network which allows subscribers to select from a fixed schedule of programs. A system like the Rediffusion system of remote controlled multi-position switches in local exchanges was used for cablecasting. Contacts in the reset positions of these switches provide access to the broadband communication system. Individual services are provided by interconnected groups of crosspoint switch arrays located in local exchanges and the central exchange. Local control logic circuits control the operation of the multi-position switches and also send service requests to the common control logic. A programmed common control computer sets up the communication circuits in the broadband communication network.

As in the Rediffusion system, all video signals are transmitted along wire pairs over a 6-Quist cable in the 1 to 10 MHz range. Running two sets of pairs to each subscriber would minimize the installation costs for broadband full duplex point-to-point communications. At the same time, the cable length between the local exchange and the most distant subscriber served by the exchange should be sufficiently short to allow the subscriber cable to operate without amplifiers. This not only minimizes the cost of the subscriber cable but simplifies broadband signal origination from subscriber terminals for two-way services.

The switching requirements for the broadband communication network depends on both the number of subscribers served by each of the exchanges and the behavior of the subscribers in placing calls on the network. These switching requirements would be the same if the network was designed around a single "centralized" exchange. However, the total mileage of communication cable in the system is significantly reduced by "decentralizing" the network switching. Long cable runs are then limited to the transmission circuits between the local exchange and the central exchange or the cablecast distribution center.

The broadband communication network uses the same general switch organization as modern telephone switching systems such as the Bell Telephone No. 1 Electronic Switching System.[2-31] The same traffic formulas used to determine the individual telephone office requirements may be used for specifying the switching requirements for the broadband communication network.[2-32]

Switching calculations were made for full two-way (full duplex) service. Receive-transmit communication service require the simultaneous use of both communication lines (two pair half-duplex). (Mathematically, each service request is treated as a single-path requirement and the calculated link requirements are then doubled to satisfy the requirement of two-way communication.) One-way individual services with an average duration of 90 minutes and a blocking probability of 0.2 would require 12 crosspoints. This would allow the subscriber to select plays or movies from a video library and is the most demanding form of one-way service envisioned. Alternatively, full two-way point-to-point individual services with an average duration of 10 minutes and a blocking probability of 0.01 would require 15 crosspoints per subscriber. Unlike the FDM system, the growth of demand for subscriber services can be met by modifying exchanges without having to lay new cable.

We assumed that cablecast television will account for most of the total system use. Since the cable subscribers will still depend quite heavily on normal telephone circuits for the majority of their personal and commercial business (the intent of the cable system is not to replace telephone service), the peak-hour traffic load for the broadband communication network should be small.

Either of two mutually exclusive plans for system growth may be used. The first approach involves minimizing switching hardware at all phases of system growth. Although relatively good switching economy can be achieved, the switching pattern will necessarily change for both the local and central exchanges in response to system growth. Each change will require alteration of the cabling pattern in the respective exchanges. This technique becomes quite cumbersome as the system is "rewired" for relatively minor changes in the number of subscribers.

The second approach involves system growth around a fixed switching pattern which minimizes switching hardware at the end of the growth period (full system subscription). Crosspoint switch elements and communication links are added to the fixed pattern to meet the peak-hour traffic load requirements of the system. No "rewiring" will be required unless the anticipated traffic load is found to be grossly in error (on the low side). This second method would seem to be preferable for developing the broadband communication network.

The relative costs of SDM and FDM systems for the same subscriber population have been estimated and are discussed in Chapter 3 of this report.

2.5 Terminal Requirements

2.5.1 Display Requirements

Visual displays differ in several characteristics: input bandwidth, format, resolution, and capacity. For example, a conventional television receiver requires an input bandwidth of about 4 MHz and is customarily used to display motion pictures. The motion picture is one example of a display format. A convenient listing of possible display formats is given below in Table 2.7.

Table 2.7 DISPLAY FORMATS

MP	Motion Picture
SP	Still Picture
LD	Line Drawings or Variable Font Writing
AN	Fixed Font Alphanumeric

The display formats have been listed roughly in order of descending bandwidth requirements. Thus, a still picture can be sent over a 50 KHz line with adequate resolution in about 60 seconds. A motion picture must be changed every 1/30 second to preserve the illusion of continuous motion. This requires a full 4 MHz bandwidth. Similarly, pictures require a wider range of tones or gray scale than line drawings or documents. Finally, great reductions in bandwidth can be made if only a fixed character set is to be transmitted.

One can not specify the bandwidth required to transmit a particular format without specifying the resolution of the transmitted image. An equally important characteristic is the size or capacity of the display. For example, the front screen of a television picture tube is composed of many small phosphor dots scanned in a sequence of horizontal lines. When these lines are scanned sequentially with an electron beam of varying intensity a visual image is produced. The capacity of a conventional television picture is 525 lines. Since the ratio of width to height (aspect ratio) of the picture is 4/3, the height of a 15" television screen is 9". (15" conventionally refers to the diagonal length of the rectangular screen.) This corresponds to a vertical resolution of 525/9 = 58 lines/inch.

Assuming that the vertical and horizontal resolutions are the same, one can estimate the number of picture elements (pels) in a television picture. This is a measure of the amount of information in a picture. There are about $(43)(525)^2 \approx 370$ thousand pels in a television picture. By way of comparison there are 500 Kpels in a frame of 35 mm film and 125 Kpels in a frame of 16 mm film.[2-33]

For motion or still picture reproduction a critical viewing distance can be defined at which the picture gives visual satisfaction. At longer distances detail is blurred while at shorter distances the line structure becomes evident. For pictures having a fixed number of lines, the critical viewing distance depends on the picture height. This corresponds to a viewing ratio (= distance from TV screen/picture height) of about 5 for most viewers. This means that watching a 12" high TV picture from a distance of about 5 feet provides visual satisfaction for most viewers.

Comfortable reading, on the other hand, demands much higher resolution -- 5 feet is not a comfortable distance for reading. 16 lines (corresponding to 8 line pairs) are needed for Excellent reproduction of the letter "e" by microfilm standards.[2-34] 10 and 6 lines per letter are regarded as Legible and Decipherable resolutions, respectively. The resolution of a typed page is 200 scan lines/inch and that of a printed page is 300 scan lines/inch. This is 3.5 to 5 times the vertical resolution of an ordinary television picture. Considering both horizontal and vertical resolution, $(3.5)^2 \approx$ 12 to 25 times the number of pels would be required to produce television pictures with resolutions comparable to typed and printed pages, respectively.

This places severe restrictions on the number of characters a television set can display. MITRE's TICCIT system accommodates 16 lines of 50 characters in approximately 260 scan lines.[2-35] This corresponds to roughly 16 scan lines per character line, which would allow good to excellent resolution of each character. The size of the TV screen affects neither its resolution nor its capacity. Compare this with an ordinary 8 1/2" x 11" typewritten sheet covered with pica characters. This has a resolution of 200 scan lines/inch and a capacity of 5400 characters in 64 lines of 84 characters. In many cases, even higher resolutions might be more aesthetically pleasing. However, a 10 line message containing a maximum of 720 characters is more typical for teletypewriter networks. This is approximately the capacity of MITRE's TICCIT system.

To summarize this discussion we distinguish four levels of resolution and capacity in Table 2.8 with the understanding that they are difficult to define precisely. We further assume that printed page resolution would allow reproduction of photographs and typewritten page resolution would allow excellent reproduction of line drawings.

Table 2.8 RESOLUTION AND CAPACITY OF DISPLAY SYSTEM

PH	Photographic
PP	Printed Page
TW	Typewritten Page
TT	Teletype Message

The presentation of motion pictures requires wider bandwidth than the presentation of still pictures. Motion pictures achieve the illusion of motion by displaying still or stationary pictures at a high rate. The required rate depends upon the apparent rate of motion of the objects in the image and the time during which each still picture persists in the mind of the observer. Persistence is the more stringent condition. Although the picture (frame) on the television screen is changed 30 times a second, it is divided into two interlaced sets of lines called fields which are changed at a rate of 60 times a second to prevent flicker. As a result, the phosphor screens in conventional television sets are designed so that even a still picture must be constantly refreshed or recreated by a scanning electron beam. More exactly, about 370 Kpels of information are transmitted every 1/30 second to maintain the illusion of continuous motion on a television screen.

Thus, the refreshment rate rather than the resolution or capacity of the display is the main reason for the 4 MHz bandwidth required for television transmission. Since facsimile displays provide a permanent record, generally a printed page, they do not require refreshment. A facsimile terminal can display documents at normal reading speed with a resolution of 200 scan lines/inch using only a 50 KHz bandwidth. That is, a facsimile display with 3.5 times the vertical resolution of a television picture requires only 1/80 of the bandwidth for transmission. Furthermore, since transmission of a permanent display would require only 1 minute, the channel could then be released to messages to other subscribers. This would allow much more efficient use of an FDM cable for the transmission of messages to individual subscribers. The necessary technological innovations are discussed more fully in Section 2.7.

The bandwidth of a coaxial cable limits the bandwidth available for transmitting services to particular subscribers. As a result, several methods have been devised for reducing the bandwidth required to supply particular services. These methods have generally involved attaching additional memory to a conventional television set so that its display could be refreshed at the terminal rather than by the distribution network. This would allow channels to be released for the use of other subscribers once the message was transmitted.

For example, MITRE's TICCIT system can transmit one video picture every 10 seconds to 600 subscribers using a single video channel.[2-35] The resulting display has a capacity of 800 characters (16 lines of 50 characters) chosen from a standard set of 96 alphanumeric characters. (This is equivelent to the character list for seven bit ASCII code.) The video image is generated by a Data Disc Television Display system from data supplied by a computer. The home terminal uses a standard television receiver coupled to a SONY AV-3400 video tape recorder. The video tape recorder (VTR) served as a memory for the television display which was refreshed 60 times a second by the VTR. The cost of such a terminal was estimated at 1.5K$ if produced on a commercial scale in 1971.[2-6] This type of terminal is sometimes called a "frame-grabber." The display contains 256 lines which is half the vertical resolution of a conventional television display since only one field (half the lines) of a complete frame or picture is transmitted. The terminal can receive still pictures or line drawings in addition to alphanumeric information. Note, however, that the transmission rate of the pictures is fixed. No bandwidth utilization advantage is taken of the fact that most subscriber services might not require the display to be updated every 10 seconds.

Another option is voice band television (VBTV) which can transmit a 128 line picture in 8 seconds over telephone lines or any other 2 KHz communications link. Pictures can be recorded on any audio tape recorder and played back on a special VBTV receiver costing 500\$.[2-36] The Picturephone developed by Bell Laboratories contains a 5 x 5.5" television display and requires a 1 MHz bandwidth. This narrower bandwidth is accomplished by reducing the resolution of the image. Each Picturephone frame contains approximately half the number of lines and each line contains half the number of pels of a conventional television frame. A more complete description of the Picturephone is given in References 2-16 and 2-37.

Such terminals can display pictures or line drawings but are not well adapted to displaying documents. Great savings in bandwidth are possible if only fixed font (one style) alphanumeric characters are transmitted. Teletypes can transmit 100 words per minute within a 170 Hz bandwidth.[2-38] To do this each character is represented by a sequence of digital bits which are translated into electrical pulses for transmission. The most popular code for communication with computers is ASCII which can represent 128 different characters or control functions using a 7 bit sequence (code).

A storage display monitor such as the Tektronix 603 will display 20 lines of 50 characters (1000 character capacity) on a 5 x 4" screen.[2-39] This unit costs 1.1K\$ (1974), but requires no VTR. It would require approximately 50 milliseconds (ms) to write a message and a 2 MHz input channel. Another option is the Tektronix 4023 Computer Display Terminal which uses ASCII Code to display 24 lines of 80 characters each on a 9 x 5.5" screen. Since it generates and restores its own fixed font characters it can accept data at rates from 110 to 4600 bps on communication channels ranging from 55 to 2300 Hz. This terminal costs 3K$ (1974) but includes a 96 character keyboard for interactive operation.

The increasing availability of inexpensive semiconductor memories and logic circuits in integrated circuit form is tending to lower the price of these units. Southwest Technical Products Corporation has developed a character terminal system CT-1024 with a storage capacity of 1024 characters, displayable in two pages with 16 lines of up to 32 characters per page. This system is sold in kit form (1975) for 175$.[2-40] It may be used with a video monitor or other TV set having a video input jack. With some accessory equipment, the CT-1024 can send data at rates of 110 to 1200 bps. Similar systems could be adapted to provide interactive services on cable television systems.

With the exception of the proposed facsimile terminal, all of these displays are inferior in resolution and capacity to typewritten or printed pages. In many cases, this reduced quality may be adequate for a particular interactive service. However, it may well be that services can be provided more effectively with a higher quality display. We will return to this question when we consider specific services in Chapter 5.

In any event, the present trend appears to be augmenting conventional television receivers with additional equipment such as video recorders to provide interactive services. Baer's report[2-41] indicated that this would be relatively expensive, with terminal costs above 1.5K$ (1971 costs) for two-way subscriber initiated services using a video display. The existence of a wide variety of alternative terminal technologies makes this a significant Technical Issue. Without encouragement or incentive, new technologies are less likely to develop and existing technologies will be modified to adapt them to ends for which they are unsuited. The situation is similar to the modification of existing automotive power plants to minimize pollution and maximize fuel economy; it is unlikely to yield an optimal solution.

2.5.2 System Requirements

So far we have only considered the downstream bandwidth requirements imposed on terminals. (By downstream bandwidth we mean the bandwidth associated with transmission from the head-end to a particular user.) Since we are dealing with interactive services, the upstream or return bandwidth needs to be specified as well. Since one usually needs to transmit only instructions to the headend, a 100 KHz data channel is adequate in most cases. In addition, services will need to be routed or addressed to a particular subscriber and in some cases information will need to be processed before it is sent to the user.

In some cases a signal needs to be sent over a return channel only to initiate the service. Continuing use of the return channel is not required. Other services may require continuing use of the data channel. For example, if a large list is to be searched by the user, the return channel will need to be used on a continuing basis. The requirements for particular services are analyzed in Chapter 5. Most services can be provided with a simple data entry device such as a Touch-Tone type of telephone hand set.

All interactive services will require message routing so that they can be addressed to a particular user. Most will require the manipulation or regular updating of data. To satisfy these requirements a computer must be included in the system which will allow both the routing and processing of messages. Thus, the interactive BCN is, in effect, a computerized information network as discussed by H. V. O'Neill.[2-42]

Message processing at the level we are considering could probably be handled by a conventional time-shared minicomputer system. For a large cable system, access to even a large computer would represent only a small additional cost to the subscriber since its cost would be shared by many.

Message addressing requires more specialized consideration and is discussed in the next section.

2.6 Methods of Supplying Data Channels for Interactive Services on Coaxial Cable

Coaxial cables limit the bandwidth which FDM cable television networks can supply to individual subscribers. This, in turn, limits the interactive services which can be supplied to individual subscribers. Because of this fundamental limitation, we made a study of technological alternatives for supplying interactive services on coaxial cable networks. This study has been reported in a special issue of the IEEE Transactions on Communications devoted to Interactive Broad-band Cable Systems.[2-43] It is summarized below.

The limited bandwidth resources of a coaxial cable can be shared between individual uses by one of two basic multiplexing methods - separating signals in time (TDM) or frequency (FDM). Which method is preferred depends on their spectral efficiency, i. e. the efficiency with which they conserve the cable's bandwidth. We have evaluated these multiplexing methods on the basis of commercially available components to minimize cost.

A severe limit on the spectral efficiency of TDM is set by cable delay. Since several terminals share the same channel, their transmissions must be synchronized so that they do not interfere. In general, this is accomplished by allowing terminals to transmit or receive only after a timing signal is furnished by the headend. As the rate at which one terminal ceases and another starts increases, cable delay becomes a factor. Terminals are no longer synchronized since they receive timing signals at different times.

A typical cable network that is 10 miles from headend to furthest point has a round-trip delay of about 150 µs. Therefore, the maximum rate at which one can switch terminals while maintaining spectral efficiency is about 300 s^{-1}. This rate can be increased to 300 000s^{-1} if delay is compensated to one percent. (One percent compensation corresponds to the accuracy limit of typical integrated circuit delay generators.) This does not solve the problem of delay completely since shifting terminals or modifying the network may require adjusting the delay compensators.

The switching rate is essentially the number of terminals that can be given transmission time in one second. If each terminal is allowed to transmit one bit, then 3000 terminals could share the cable at one time with each terminal transmitting at a rate of 1 bit/s! Obviously, each terminal must transmit many bits in a block to obtain reasonable bit rates.

As the number of bits per block goes up, the bit rate sent and received with each block goes up, with a limit being set by terminal circuitry. To lower cost, TDM terminals must use large-scale integration (LSI). Since the maximum clock rate of an LSI circuit is presently about 3 MHz, the maximum bit rate of a low-cost TDM terminal would be about 3 Mbps (3 million bits per second). In a TDM system with 3000 terminals and a bit rate of 3 Mbps, each terminal could transmit a 100-bit block in one second for an effective bit rate of 1 kbps. This effective bit rate can only be increased by multiplexing fewer terminals on the same channel.

In FDM each signal is modulated; that is, it is translated in frequency so that it occupies a particular channel or segment of the cable spectrum. In FDM the signal generally has exclusive use of the assigned segment as long as the assignment lasts. Modulation results in spectral inefficiency since the modulated signal will consume more bandwidth than the original signal.

The spectral efficiency or packing density of FDM is determined by several factors: modulation type, terminal filters, and carrier drift. Optimization of terminal cost and spectral efficiency have been addressed by commercial radio manufacturers and the FCC for many years. Any proposed FDM scheme for BCNs should be based on this experience.

Commercial two-way FM components can be used to implement an FDM system for data transmission. The stability of crystal oscillators then sets a lower limit on spectral efficiency as follows. Crystal oscillators have an accuracy of ± 0.001 percent, independent of frequency. This corresponds to a maximum deviation of ± 2 KHz for a 200 MHz carrier. The separation between carrier frequencies must be expanded to allow for this error. This sets a practical lower limit on bandwidth of about 1 KHz if reasonable spectral efficiency is to be maintained with a carrier on the order of 100 MHz. Lower carrier frequencies would, of course, allow lower bandwidths. (Alternatively, the problem of crystal oscillator instability can be eased by using phaselocked loops to slave each terminal to functions of a centrally generated master frequency. This would be more expensive, but offers advantages for dynamic allocation as we will show later.)

Comparing TDM and FDM we note that since TDM is inherently digital it is more suitable for digital than analog transmission. Analog signals can be digitized but conversion involves a loss of spectral efficiency as discussed in Section 2.4.3. Because of crystal instability, FDM tends to have a lower spectral efficiency for multiplexing signals with base bandwidths below about 1 KHz. Conversely, TDM systems tend to lose spectral efficiency due to uncompensated delays and clock rates for bit rates of about 10 Kbps for each terminal, depending on the particular system. Thus, it appears that TDM offers particular advantages for low speed digital signals, while FDM offers particular advantages for higher speed analog signals.

Both TDM and FDM methods have been used in interactive communication systems. The Sterling Manhattan FDM system allocates a fixed channel to each subscriber (static allocation). The MITRIX TDM system[2-45, 2-46] assigns channels on demand, permitting more efficient use of the cable bandwidth (dynamic allocation). Static allocation is analogous to leased-line telephone service, while dynamic allocation is analogous to private-line telephone service.

Although both systems were designed to provide point-to-point two-way digital communications, each falls within the limits set for their multiplexing method defined above. The MITRIX TDM systems has a switching rate of $3200s^{-1}$ which is an upper limit for a 10 mile cable without delay compensation. An effective data rate of 100 bps can be achieved if one block is assigned to each of 8192 users. Higher effective bit rates are available if more than one block is assigned to a user. The Sterling Manhattan FDM system uses a 6 MHz bandwidth for upstream and downstream transmission. This bandwidth is divided into channels capable of carrying 1.2 to 50 Kbps. Channels carrying more than 50 Kbps could be provided but were not in demand.

Since most users do not communicate continuously, communication channels do not need to be allocated permanently. It is more efficient to dynamically allocate bandwidth to users on demand. For example, the telephone company finds that only about 10 percent of the total number of subscribers will want to use its facilities at peak times. By using dynamic allocation, the telephone company needs only one tenth of the interoffice trunks required if one were assigned to each subscriber. Similar estimates can be made for a BCN and will be discussed in Chapter 5 of this report.

To achieve these savings there must be a machine to take requests from users or user terminals, analyze their validity, execute the request, communicate with both calling and called terminals to specify the channel to use for the communication, and reset the system when the call is finished. If we call such a machine a dynamic allocator, then we can talk about the exchange of information between terminal and allocator in addition to the desired communication service. The dynamic-allocation system must transmit request signals from the terminal to the allocator and control signals between the allocator and the terminal.

In a conventional space-division multiplexed (SDM) telephone system the same telephone line carries communication, request, and control signals. Conversation is a communication signal while taking a telephone "off-hook" generates a request signal. Ringing, dial tone, and dialing are all control signals. (Note that the first two are generated by the allocator (a switching exchange) while the third is generated by the user. Thus, provision must be made for two-way transmission of control signals between allocator and terminal.) In a BCN, it will generally be advantageous to carry these signals over different channels. This is because the dynamic allocation process is more complex in a BCN where the use of different bandwidths for different services would result in more efficient utilization of the available spectrum. Moreover, a more economical system may result if the multiplexing scheme for request or control channels is different from that for communication channels.

There are several methods which an allocator can use to identify requests from terminals. Two of particular interest are polling and interrupting. In a polled allocation system the allocator polls all terminals in sequence to determine their status. In an interrupt allocation system a terminal can request an allocation if the allocator is not busy.

A polling scheme is inefficient if the terminals respond with no requests most of the time. Interrupt allocation shifts the timing burden to the terminals by having them send requests to the allocator. Once the allocator detects the start of the request, it must send a busy signal to all other terminals to prevent interference.

A TDM interrupt scheme is more efficient for occasional requests but introduces the problem of interference between simultaneous signals. While the bandwidth required to process control information depends on the traffic, we estimate that a 1 Kbps control channel should suffice.

The Technological Issue we have addressed is the relative merit of alternative technologies for providing data channels in a coaxial cable BCN. TDM is more practical at data rates below 10 Kbps while FDM is more practical at data rates above 1 Kbps. Bandwidth can be conserved by dynamic allocation rather than the permanent assignment of channels. To provide dynamic allocation, however, requires increased expenditure for a control system.

Assuming one desires interactive services, the choice of multiplexing scheme depends upon the data rate requirements of particular services. Whether or not one needs dynamic allocation depends on the traffic or level of demand for those services. Thus, the decision between alternative technologies depends upon an estimate of the demand for data transmission over BCN. We will make a quantitative estimate of these requirements in Chapter 5. Note that the considerations of this section do not apply to SDM BCNs because there is no need to conserve bandwidth.

2.7 IMPACT OF TECHNOLOGICAL INNOVATION ON BROADBAND TELECOMMUNICATION SYSTEMS

In this section we consider the effect particular innovations may have on the development of broadband telecommunication networks. For the purposes of this section we regard any innovation which reduces the cost or improves the performance of a BCN to be an improvement. We consider two innovations, optical communications and facsimile, which could have a major influence on BCN technology. The summaries in this section are abstracts of more complete reports prepared or in preparation. Since neither of these innovations presently exists in a form suitable for immediate application to broadband communications, these reports are extrapolations of present technology and forecasts of future technology. In both cases we introduce the technology, describe it in depth, and indicate its impact.

2.7.1 Optical Communications

Optical communications, in their most rudimentary form, date back to the use of smoke signals by primitive American Indian tribes. Today, simple techniques such as blinking lights and waving flags are still effective methods for line-of-sight communications between ships at sea. The heliograph,[2-47] used extensively during World War I, was used to flash pulses of reflected sunlight by means of a shuttered mirror over distances in excess of 100 miles. All of these early optical systems were digital in nature, and characterized by a very low data rate because of their manual operation. However, intensity modulation with speech signals was accomplished prior to World War II, by using an electronically driven reflecting diaphragm as a mirror. In this way, information bandwidths of a few thousand cycles per second (up to 3 KHz) were achieved at that time.

In recent times, the invention of the laser has opened up the possibility of achieving an increase in bandwidth by as much as a factor of a million. This has given rise to major research and development efforts on all component parts of optical communication systems, so that they now provide attractive possibilities for use in broadband communications. In addition, the development of low-loss optical fibers has virtually assured the role of optical techniques in communication systems of the future.

Any evaluation of optical communications must consider all of the components of optical links which may be used in any part of these systems. These include:

- the optical power source and the physical techniques for its modulation,
- the modulation scheme which can be used,
- the optical fiber medium through which the signal travels and how signals are coupled with it,
- the detection means at the receiving end, with conversion into an electronic signal, and
- provisions for repeaters if necessary.

The separate analysis of each of these areas follows. Incidentally, it is not immediately apparent as to which parts of a conventional cable television system are directly replaceable by optical means. In fact, it is possible that optical techniques may be best suited to unconventional cable systems.

2.7.1.1 Optical Power Sources and Modulators

The solid-state light source[2-48] is today the only significant contender for this application since it combines the advantages of high intensity, small size, and low cost. Both incoherent and coherent sources are possible.

The Light-Emitting Diode or LED is the most commonly available incoherent source. Incoherent sources, for indicator lamp service, are already on the open market (1975) at under 20 cents each. Devices specifically designed for optical fiber coupling should be commercially available in the next two to three years, at somewhat higher prices.

The Semiconductor Injection Laser and Solid State Ion Laser are the most common candidates for coherent sources. In its simplest form, the Injection Laser is an overdriven LED with an optical cavity. The output is coherent, and is thus suited for efficient coupling into single-mode fibers. The long-term advantage of injection lasers lies in their potential for direct modulation at gigahertz frequencies. Thus, they open up the possibility of a ten-to hundred-fold increase in the channel capacity of cable TV systems. At the present time, however, these lasers are plagued with reliability problems. Their practical realization is about ten years into the future.

The Solid State Ion Laser is a second coherent source that is suitable for optical communications. The potentially most useful one is the neodymium-doped, yttrium-aluminum-garnet (Nd : YAG) laser. The emission spectral width of this laser is narrower than that of the junction laser; furthermore, it is in a sufficiently advanced state of development so that reliable operation can be sustained for thousands of hours. Recently, miniature[2-49] Nd : YAG lasers have been made using 1 - 2 cm length silica fibers with Nd-doped cores of less than 1 μm diameter. These lasers hold great promise for use in fiber-optic communications since they require low input power, can be pumped with a solid state LED, and deliver high radiance within a small cross-sectional area.

All of the highly developed radio modulation schemes can be applied to optical signals also. Thus, analog and digital modulation schemes can be used, in addition to pulse code modulation. At the present time, it appears that the analog modulation of optical signals will be applied to cable television systems, where line lengths are not large enough to warrant the necessity of going to a digital format. Intensity modulation is the most promising analog scheme today, since it is extremely easy to implement with both solid state LED's and injection lasers. In addition, the detection of intensity-modulated optical signals is relatively straightforward with solid state photodetectors.

Frequency, phase, and polarization modulation schemes lend themselves more readily to external modulator techniques, and may find favor with solid state ion laser power sources. However, their general use is only expected with coherent power sources, which are at least ten years into the future.

The quantity of raw materials used in optical power sources and modulators is extremely small. As a result, there are no restraints on their usage in optical communications.

2.7.1.2 Transmission Media

Optical signals can be sent through the air, and large distances can be covered under favorable atmospheric conditions. In practice, however, the uncertainties associated with air turbulence, environmental pollutants, and weather conditions makes this method of transmission only useful over path lengths of one to two miles. Consequently, these signals must be confined to controlled transmission media if they are to travel over larger distances.

One approach consists of transmitting the optical signal through a large tube filled with a dry inert gas such as nitrogen or argon. For this situation, the beam is essentially "free," and precise alignment is required to keep it within the tube. Although mirrors and prisms can be used for beam control, serious alignment problems are encountered as a result of mechanical vibrations and temperature gradients in such systems.

Handling problems can be greatly relieved by resorting to ultraminiature structures, fractions of a millimeter in diameter, consisting of a glass core surrounded by a cladding of lower index of refraction. These fiber-optic waveguide structures are commonly known as optical fibers.

The actual distance that a signal can be transmitted before reamplification is a function of the physical properties of the fiber. As recently as[2-50] 1968, the typical loss in a glass optical fiber was in excess of 3000 dB/km.* It is generally considered that losses must be kept below

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*Note that 10 dB represents a transmission of 10%, while 20 dB represents a transmission of 1%.

20 kB/km if serious consideration can be given to their use in telecommunication applications.

A special low loss silica optical fiber recently developed by the Corning Glass Works,[2-51] exhibits an attenuation of only 4 dB/km over selected wavelength ranges. This is well within the prescribed loss figures required for effective telecommunications usage, and fiber must be considered as a practical alternative to cable in this area.

Other materials can be used for fiber-optic waveguides. Plastics are commonly used because of their low cost and ruggedness. However, the best loss figures, as of 1974, are in excess of 1000 dB/km. Liquid-filled fibers have[2-52] also been announced, with losses on the order of 7.3 dB/km at 1.08 microns. Hollow tube fibers have been announced by the Bell Telephone Laboratories,[2-53] and exhibit optical loss of as low as 5 dB/km. Lengths in excess of one mile (1.6 km) have been drawn in one continuous fiber. A number of alternate techniques for splicing broken fibers are under active development in laboratories in the United States.

The information handling capability of an optical fiber is limited by the fact that the path length of a ray is a function of the angle at which it travels down the fiber. For fibers of the unsupported single material type, the useful bandwidth is only 200 kHz/km when used in a multi-mode structure.

Up to now we have only considered fiber-optic waveguides in which the refractive index of the core is uniform. It is also possible to build structures in which the index of refraction of the inner conductor is graded, high along the axis and falling off gradually near the cladding.

Increased bandwidths of 650 MHz per km are possible with graded fibers. These fibers are made[2-54] by subjecting the fiber to an ion-exchange process by immersion in a suitable molten salt. Absorption losses in the fiber are relatively high because of the presence of this ionic component. A commercial version,[2-55] known as SELFOC (self-focusing), available from the Nippon Electric Company, Japan, has an outer diameter of 1.5 mm and an attenuation of 20 dB/km. At the present time, this cable is only available in 200 meter lengths, but this situation will certainly change as the technological process becomes more developed.

Recently, Bell Labs have announced an inverse-parabolic-graded fiber[2-56] with a bandwidth of 600 MHz per km, and an attenuation of 6 dB/km. The bandwidth performance of this fiber has not been satisfactorily explained, but it is felt that mode mixing effects cooperate to reduce the dispersion in this situation.

Fiber-optic waveguides can also be constructed to support a single propagation mode. Such fibers have the greatest long range potential for wideband, low loss propagation. To use them, however, requires that they be coupled to a coherent optical source, and that the inner core diameter be extremely small. The fabrication of such fibers, and efficient coupling to light sources, is a difficult technical problem.

The bandwidth characteristic of single mode fibers is limited by pulse broadening due to dispersion. For typical single mode fibers, this is in excess of 100 GHz per km, and is 400 times the bandwidth of a kilometer of modern copper cable of the type used in CATV applications.

The unsupported single material fiber announced by Bell Laboratories[2-53] is of sufficiently small diameter to be used for single mode transmission.

From the foregoing discussion, it can be seen that the uniform refraction index, multimode fiber-optic waveguide is restricted to bandwidths of 10 MHz/km. On the other hand, the bandwidth of a typical parabolic-graded, multimoded fiber is 650 MHz/km. Finally, bandwidths in excess of 100 GHz/km can be transmitted in single mode fibers.

Table 2.9 CABLE PERFORMANCE DATA

Cable Type	Loss	Bandwidth
Trunk (3/4" coax)	32.8 dB/km at 250 MHz	250 MHz
Feeder (1/2" coax)	65.6 dB/km at 250 MHz	250 MHz
Corning uniform fiber (multimode)	4 dB/km at 1.06 μm	10 MHz/km
Bell Labs air supported fibers (single mode)	5 dB/km at 1.06 μm	100 GHz/km
Nippon SELFOC graded fiber (multimode)	20 dB/km at 1.06 μm	650 MHz/km
Bell Labs inverse graded fiber (multimode)	6 dB/km at 1.06 μm	600 MHz/km

Table 2.9 compares the attenuation and bandwidth of various coaxial cables at 250 MHz with the values for optical fibers in the 1.06 micron range.

2.7.1.3 Photo-Detectors and Detector-Amplifier Combinations

The reception of an optical signal is accomplished by means of a photo-detector, which converts this signal into an electrical one.

The photo-emissive effect is one that can be exploited for this purpose. Both vacuum photo-diodes and photo-multipliers can be used over the spectral range from 0.2 to 1.1 microns, i. e., the range covered by modern light sources.

From a cost point of view, the most attractive candidate for optical signal detection is the solid state photo-detector. Here, the silicon device is pre-eminent in its linearity, and its wide dynamic range. In addition, its low cost and long term stability are already well established.

The detection limit of a typical device, operating at room temperature, is about 10^{-15} watts.[2-57] This same device can detect signals as large as 10^{-2} watts without saturation, resulting in a dynamic range of 13 decades. This is well in excess of the requirements imposed on detectors by any existing method of modulation that can be used for optical communications.

The speed of response of a silicon photo-diode is typically in the 1 - 2 nanosecond range. Thus, it is capable of handling signal bandwidths in excess of 250 MHz, the full bandwidth which is normally transmitted in a cable television system.

The spectral response of a photo-detector is governed by its energy gap. For silicon, this results in usable performance over the wavelength range from 0.2 to 1.1 microns. Thus, it is well suited for coupling to fiber-optic waveguides, and can be used with all presently available light sources.

The greatest potential of the silicon photo-diode lies in the ability to integrate it with its associated electronic circuitry into a single silicon chip. Both detectors and circuits can be made by the same basic process which is used for fabricating microcircuits. Thus, the potential cost of a monolithic optical detector-amplifier combination should be comparable to that of any other microcircuit of similar chip area ($1.00 - 2.00 range) in 1974. We do not expect the price to fall far below this value over the next ten years, because of inherent limitations of chip size.

Monolithic detector-amplifiers to cover the full 0-250 MHz range are not foreseeable at the present time, because of inherent parasitic capacitances associated with this technology.[2-58] However, hybrid detector-amplifier combinations already capable of this bandwidth, are a distinct possibility. Merit, Inc., of Santa Monica, California[2-59] has developed a photo-detector-amplifier combination for use in the 0.9 to 1.06 micron range, with a 60 MHz bandwidth. Moreover, hybrid technology is rapidly advancing, and it is expected that a 250 MHz unit will certainly be available within five years time. This is a safe assumption, since hybrid amplifiers of this bandwidth are already commercially available from Avantek[2-60] and from Microwave Semiconductor Corp.,[2-61] at $50. to $100.00 each. Over the next ten years, we can expect a cost reduction to about $5.00 for these amplifiers.

Trunks represent a promising area for optical techniques in a frequency division multiplex system, over the five-to-ten year time span. The primary advantage here is that of increasing the spacing between repeater amplifiers, and allowing longer trunk lines to service a larger area. The use of these techniques should raise the break-even distance (7 - 10 miles) between cable and microwave for head-end links by a factor of 2 in ten years time.

Optical communication techniques will not have an impact on feeders in the foreseeable future. Techniques for tapping optical fibers in a commercially satisfactory manner will only be available in optical integrated circuit form, which is more than ten years into the future.

Finally,[2-62] conventional cable is made from copper, a mined commodity which has been steadily increasing in price as the average yield of copper ores falls. Thus, the price of copper per pound was 32.1 cents in 1960, 58.2 cents in 1970 and $1.00 in February 1974. Optical fiber, on the other hand, is made from sand, an almost limitless commodity. Moreover, the energy required to produce equal lengths of optical fiber and trunk grade copper cable are on the order of 1 : 9000.

In recent years, aluminum has been considered as a viable alternative to copper for cables, since this metal is perhaps the second most commonly available element on earth. The weight of aluminum used in cables is usually the same as that of the replaced copper, for the same electrical performance. However, it takes 6 pounds more of coal to refine one pound of aluminum than it does for one pound of copper. Thus, the impact of optical fibers on both mineral and energy resources is considerably less than that for conventional copper or aluminum cables.

2.7.1.4 Optical Integrated Circuits

The optical integrated circuit will undoubtedly play an important role in communication systems of the future. Devices are now being developed which will provide the important functions of signal generation, amplification and detection, all at the optical level. Ultimately we can hope for an optical signal handling system of the same cost and reliability as the modern integrated circuit, but with vastly greater bandwidth capabilities. However, we do not envision the emergence of such circuits from the research laboratories for the next decade. Certainly, the use of optical techniques in cable television systems will first take the form of optical fibers for transmission, with electro-optical coupling components at each end. Integration will thus only be employed at the electronic level during this ten year period.

2.7.1.5 Impact

The use of optical fibers in communications presents many attractive features. These include:

- large bandwidth, resulting in increased communication capability;
- low loss, with increased repeater spacing;
- small size and weight, for ease of installation;
- absence of cross-talk between fibers, and pickup from noise pollution sources in the environment; and
- difficulty of tapping, resulting in secure systems.

Space division multiplex systems represent an ideal situation for the use of optical communication techniques, over the next three- to five-year time span. Here, the use of optical techniques should reduce the number of local exchanges by a factor of 15 or more, and allow the use of expanded two-way services over a local section of a conventional cable television system. All of the components for its implementation are available today, with an incremental investment cost of one to two dollars a subscriber.

2.7.2 Facsimile

Facsimile, the electrical transmission of printed messages, has existed since the early days of telegraphy. Originally, an electrified wire passed across the original document translating the conductance changes in the image into an electrical signal. The receiver and transmitter were synchronized by swinging pendulums. Although the basic principles of facsimile transmission remain the same, there have been several innovations in facsimile technology.

In modern office facsimile machines such as the Xerox Telecopier 400, the page to be transmitted is wrapped around a cylindrical drum which rotates while an optical pickup scans its length. Synchronization is maintained electronically after phasing signals sent by the transmitter are acknowledged by the receiver. To convert the electrical signal to a visible image a high voltage stylus scans the length of electroresistive paper rotating on the receiver's drum. The speed of rotation determines the horizontal resolution. (The Xerox 400 Telecopier takes 40 ms to scan one inch.) The speed of stylus motion determines the vertical resolution. (The Xerox 400 Telecopier has a vertical resolution of 96 scan lines/inch when scanning a page in 6 minutes.)

2.7.2.1 Present Facsimile Technology

The two factors of greatest importance in facsimile systems are the reproduction time (T) and the resolution (R) or quality of a copy. These factors are directly related for a given bandwidth (B). That is, the resolution of a copy is proportional to the time it takes to reproduce it. Mathematically,

$$R = k\,B\,T$$

where k is a constant.

The Xerox 400 Telecopier, designed to operate within an effective telephone network bandwidth of approximately 2 KHz, can scan a page in 6 minutes at a resolution of 96 lines/inch. For a given bandwidth, transmission time can be decreased three ways. The drum rotation speed can be increased, corresponding to decreased horizontal resolution. The stylus speed can be increased, corresponding to decreased vertical resolution. (The vertical resolution of the Xerox 400 Telecopier is reduced to 64 scan lines/inch for a 4 min/page transmission.) Finally, additional electronics can be used to eliminate unnecessary information (e. g., alternate encoding and white space skipping).

The major limitation on the speed and resolution of present facsimile systems is imposed by the narrow effective bandwidth (≈ 2 KHz) of the telephone network.[2-63] The BCN provides much higher quality channels as was discussed in Sections 2.4.2 and 2.4.3. Going to higher bandwidths allows increased speed and resolution. The Xerox LDX, although no longer in production, was designed to operate over a 48 KHz channel, sending a page in 1.1 min with a resolution of 190 lines per inch. Some other systems are designed to operate over 15 KHz lines and have intermediate speeds and resolutions.

2.7.2.2 Extrapolations of Facsimile Technology

Increasing the effective bandwidth from 2 to 50 KHz would allow R to be increased or T to be decreased by a factor of 25. This would allow significant improvements in both the speed and quality of facsimile transmission. *Doubling* the resolution from 96 to 192 lines/inch would provide the same resolution as a typed page (about 200 lines/inch). Doubling both the horizontal and vertical resolution would quadruple the amount of information to be transmitted in a given time. This would still allow transmission times to be reduced by a factor of 6 from 6 min to 1 min/page. This corresponds to 3 times normal reading speed.[2-64]

Tripling the vertical and horizontal resolution from 96 to 288 lines/inch would allow a page transmission time of about 2 min. Since the resolution of a printed page is about 300 lines/inch, this means we would be able to transmit documents over a 50 KHz channel with the crispness and clarity of a printed page at speeds 50 percent greater than normal reading speed! This speed could be doubled by simple modulation and coding methods. Since 100 such channels could be accommodated within a single video channel we see that higher quality facsimile would be an excellent replacement for video for many interactive services.

A high resolution CRT display such as the XDS 7580 has twice as many lines as conventional television, 1024 lines, corresponding to 102 lines/inch for a 10" x 10" display. Such a display has no higher resolution than conventional facsimile systems such as the Xerox 400 Telecopier. The major difference between video and facsimile displays is the refresh rate, as discussed in Section 2.5. This requirement, not the resolution or information capacity of each picture, is the reason for the much larger bandwidths associated with video displays.

The fact that a facsimile display is inherently stable makes its continual refreshment unnecessary. Conventional television is needed to transmit material such as movies whose pictures need to be changed rapidly to simulate motion. However, high-speed facsimile would allow the transmission of documents for study without significant delay in a small fraction of the bandwidth required for television.

Unlike the alphanumeric displays discussed in Section 2.5, facsimile displays can reproduce any document, regardless of type font. One could develop a machine similar to a xerographic copier which would scan any document and convert the optical image to an electrical signal for transmission to a facsimile terminal. The quality of the displayed document would be similar to that produced by a xerographic copier. (It is probably worth noting that the Xerox Copiers and the Xerox 400 Telecopier use very different, even incompatible technologies, although their names are similar and their manufacturer is the same. On the other hand, the recently announced Xerox Telecopier 200 does incorporate xerographic copier technology.)

So far, we have discussed the development of a high speed, high quality, and hard copy facsimile terminal. This would provide a permanent record of the document which would be essential in many applications. Alternatively, a soft copy facsimile terminal could be developed which would display an erasable image comparable in quality to a printed page. Considering the relative simplicity of the technology, an interactive terminal of this type probably could be produced for sale at a price comparable to that for a conventional black and white television set. (The electrostatic imaging technology to produce such a device already exists in xerographic copiers.) Terminals which allow production of a hard copy if the viewer wished, could also be developed.

2.7.2.3 Impact

The impact of facsimile technology depends on several interrelated factors. The first factor is the extent to which interactive services require reading text in contrast to viewing pictures. We expect most interactive services to depend more heavily on reading than viewing. This will be discussed further in Chapter 5.

Assuming that text reading is required, one may choose between fixed font alphanumeric displays with limited resolution and capacity displayed on conventional television receivers and a high resolution display comparable to a conventional printed page. Several factors must be weighed in making this decision.

1. The alphanumeric display is a natural extension of existing television and integrated circuit technology. A significant development effort would be required to produce a facsimile display of the type discussed above.

2. Facsimile images can be produced by optically scanning existing documents while alphanumeric displays require keyboard entry. (By keyboard entry we mean that the operator of the system must type information from the document to be displayed on a keyboard which enters the characters in a computer memory.) Thus, the entry procedure requires more human effort and skill for an alphanumeric display than a facsimile display. Thus, facsimile displays would be advantageous in a remote library situation where one would like to display information with a minimum effort required to prepare the information for display.

3. On the other hand, less computer memory is required when the information from a document can be stored in alphanumeric form. Moreover, alterations in the text of a document are

> more easily made when the document is stored in alphanumeric form. (Alterations include correcting errors or updating information. In some cases one may want to protect the original copy of a document from alteration.) Alphanumeric display would be advantageous in situations where a limited amount of information is displayed and the information is frequently updated.

The choice of display depends upon the particular application. Conversely, if only alphanumeric displays are available, interactive services will have to be modified to make them suitable for alphanumeric display. Although general guidelines like the above can be given, the choice of a display for any particular application requires careful engineering calculation. The choice will remain a moot point, however, without further developments in facsimile technology. Since present facsimile terminals are limited by telephone bandwidths, they are probably too slow and have too low a resolution to be serious competitors to video displays augmented by alphanumeric characters. If facsimile displays were developed, they could be an attractive alternative in applications requiring extensive reading. This development may be slow without appropriate incentives to facsimile manufacturers.

Over the long term a capability of remote document retrieval and display could significantly alter present patterns of information usage as measured by paper flow. Reductions in paper usage, however, require the replacement of present uses of paper by interactive services on BCNs. This is a complex issue which requires further study. One would have to examine both the present patterns of paper usage and a wide range of technological replacements.

For example, a preliminary study of the replacement of the present student record system at Rensselaer (5,000 active and 75,000 inactive records) by a computer and microfilm facility indicated some benefits but increased costs at 1974 prices.[2-65] To reduce costs, a larger volume of records would need to be processed. Until such a replacement is made, it would be difficult to distribute this information on a BCN. Even assuming that operations were computerized, one would still have to compare the cost and effectiveness of BCN distribution with the present practice of calling the office by telephone to ask a clerk for the information. Similar considerations for other applications make the probable extent of changes in paper flow difficult to assess.

2.8 Influence of Interconnection on Cable Television Practice

2.8.1 The Problem

A conventional frequency-division-multiplex (FDM) cable television system consists of head-end equipment and a distribution network. Program material is picked off the air from local broadcast stations using highly directional VHF and UHF antennas, imported using microwave common carrier, or generated locally. In general, cable systems are isolated from one another. Any interrelation between two or more cable television head-ends is referred to as interconnection.

Interconnection covers a wide range of issues impacting cable television practice. These can be grouped in three categories:

A. Large urban cable systems interconnected using either "super cable" trunks or terrestrial microwave for local distribution of some programming material (hub design), i. e., REGIONAL CABLE SYSTEM DESIGN.

B. Nationwide cablecasting network interconnected using satellite transmission for distribution of prime programming such as first-run movies and feature sporting events, i. e., NATIONWIDE PROGRAMMING DISTRIBUTION.

C. Point-to-point intersystem interconnection allowing either point-to-point wideband data (or video) or one-way wideband data (or video) with return narrowband data (or video), i. e., INTERSYSTEM POINT-TO-POINT.

These issues are arranged in the order of decreasing current technical viability, and have different impacts on cable television practice in the short and long terms. This report addresses the technology influencing development in these three areas, describes additional factors affecting growth, and discusses the impact on cable television practice.

Traditionally cable television franchises have been granted by local municipalities independent of franchise awards in surrounding areas. As long as cable television services were restricted to distribution of entertainment television, this isolation did not limit service capabilities. However, as local cable television franchises evolve to provide two-way services, the lack of interconnect capability can restrict some types of service.

Although the incompatibility of various system equipments can compound the interconnect issue, there are limitations of the technology that cause problems even with a regional cable system having compatible equipment. The principal technical limitation of wired interconnects is attenuation of the coaxial cable. While this attenuation can be offset by using amplifiers in the distribution network, the resultant build up of noise and intermodulation distortion prevents indefinite extension. With current amplifier and cable technology, 20 to 30 amplifiers can be placed in series on a standard trunk, thus limiting individual trunk lengths to 10 to 15 miles. In urban areas with multiple living dwellings, this length can be appreciably reduced by attenuation in the taps needed to serve individual subscribers. Since only minor improvements in these technologies are anticipated, long-distance interconnection of cable systems must use other technologies.

Whether a large urban system is using multiple head ends, a nationwide cable television channel is distributing its programs, or local cable television networks are used for intersystem data or facsimile transmission, some means of head end interconnection is needed. Presently the most viable technologies for these applications are super trunks, terrestrial microwave, and satellites. In this analysis the influence of interconnection development on cable television practice is described and the status and trends in these technologies discussed.

2.8.2 Regional Cable System Design

Regional cable systems are desirable in areas which are too large to be served by a conventional FDM single head end. Usually these are designed before cable franchises are released, such as the Rand design for the Dayton Miami Valley[2-11] and the Cable Television Information Center design for Jacksonville.[2-66] When the regional design spreads across municipal boundaries, long range regional possibilities are often sacrificed for short range local interests.

The often-stated principal advantage of regionalization is that less densely populated suburban areas can be provided service economically, while with many smaller systems only the systems in densely populated areas are viable. Although it may appear that the cities pay for the suburbs with such a regional network, there is overall lower system cost with a properly designed regional system. Therefore, the net effect is a similar urban cost with a lower suburban cost for basic cable service. Independent of the degree of urban subsidizing suburban cable service, the potential consumer market for home interactive service is enlarged as the number of subscribers is increased. The evolution of cable television from community antenna television into a broadband communications network (BCN) would be aided by such a market expansion.

Regionalization may also be desirable if expensive home terminal equipment required for many interactive services is shared rather than owned individually, as suggested in studies by MITRE.[2-67, 2-68] A larger subscriber base should permit better service at a fixed cost or lower cost for a fixed quality of service. It is well known from traffic theory that larger numbers of users and proportionally larger numbers of shared facilities result in higher facility utilization and thus more efficiency. Quantification of this advantage is difficult at this time since the terminal equipments and system concepts are in a state of rapid development. However, since terminal equipment cost will be the limiting factor in the early growth of interactive services, any cost reduction will aid the evolution of cable television into a BCN.

We believe that regionalization can have an even larger effect on this evolution than is generally accepted. This hypothesis is based upon our belief that cable television networks will provide local loop common carrier service to the business community as a necessary intermediate step before providing home interactive services. Initially, business use is anticipated to be the transfer of data between branch offices and other non-voice communication at the local level. In this evolutionary phase the demand of the business community will be greatly dependent upon coverage provided by the cable system. Thus a regionalized cable system could be an asset to a region in the late '70's to early '80's time frame in attracting commercial business. This projection concurs with the recently released Whitehead[2-69] report, in which common carrier status for cable television was proposed when 50 percent of the households have service in the mid to late 80's. Obviously forward looking regions could be anticipated to have such facilities earlier. Recently, designs have been proposed to incorporate this capability in conventional FDM cable systems.[2-70, 2-71] However, when we consider that Los Angeles County is served by 100 headends, operated by 40 different franchises, the problem of regional interconnect is apparent.

The technology required by regional interconnects is well developed. Presently there are two viable alternatives: "super trunks" and terrestrial microwave. "Super trunks" are special trunk designs. using bigger diameter (therefore, lower attenuation) coaxial cable, better amplifiers (lower noise and lower intermodulation distortion), or only the lower portion of the bandwidth of the trunk (to lower attenuation which increases as the square root of frequency). Such techniques can be used to connect local headends or hubs over distances of 20 - 25 miles, at somewhat larger per mile cost than typical cable trunks. Terrestrial microwave uses over-the-air transmission in the microwave spectrum (typical bands allocated for common carrier service of various types are centered near 4000 MHz, 6000 MHz, 11000 MHz, or 14000 MHz), compared with "super trunks" which use the VHF spectrum (typically 54 - 270 MHz, although the band may be reduced to minimize attenuation as previously described). Terrestrial microwave is capable of 15-to 30-mile single-hop distances, depending upon the terrain, weather, and frequency band.

Both super trunks and terrestrial microwave have a place in regional design. Principal factors include the geography of the interconnect problem (in particular, distances and terrain), the information bandwidth to be transferred, whether the interconnection is designed during cable system design or is retrofitted afterwards (microwave station costs are approximately 20 K$ while the cost of a super trunk is roughly 4 K$ per mile if installed during system installation and perhaps 6 K$ per mile if retrofitted), and the particular microwave band allocated.

Although tradeoffs are critically dependent upon the local environment, the aspect of frequency band allocation should be mentioned. Presently the FCC has allocated the 12.7 to 12.95 GHz band, called the CARS band (community antenna relay station), for terrestrial microwave interconnection. Although equipment has been developed by many companies (for example, Theta Com, Microwave Associates, Varian, and Laser Link), factors such as equipment and communication reliability need to be improved. Although lower frequency bands would be desirable from a technical viewpoint, the shortage of available spectrum and the relative importance of CARS service has led to the present assignment.

In summary, while the technology for providing regional interconnection is available, its cost and lack of immediate payoff has inhibited its growth. In addition, municipalities have granted franchises based upon entertainment service capability only, with a resultant incompatibility of equipment within a regional area. This lack of vision inhibits future service capability and retrofitting of some equipment would be required in some areas. However, regionalization would assist the acceptance of common carrier local loop service by the business community. Such a service would be a critical step in the evolution of cable television into a broadband communications network. Encouraging regionalization would hasten the evolution of BCNs from CATV.

2.8.3 Nationwide Program Distribution by Satellite

While regional cable systems have a potential impact on cable television practice, an interconnection issue of immediate concern is nationwide distribution of programs. The delivery of a greater variety of programs has been the key to the growth of cable television for 20 years, and, irrespective of future evolution into a BCN, will undoubtedly be a principal factor in determining short term growth. Domestic communication satellites have the promise of being an economical solution to the distribution of program of a nationwide interest.

In the late 60's and early 70's designs were put forth for low cost receiver terminals (about 25 K$ depending upon performance characteristics) that could be used for reception of programs relayed from a satellite in synchronous orbit. Although at least one design was for a complete satellite devoted to nationwide distribution of six channels,[2-72] the cost of program material (entertainment or educational) would appear to indicate a more modest start-up using one, or at most two, channels leased from a general communication satellite. However, the latter approach leads to higher cost receiver terminals because of a different design philosophy in common carrier satellite systems. In these systems there is usually an equal number of transmitting and receiving sites, while in the lowest cost cable-television-distribution-only satellite system there are relatively few transmitting sites (perhaps only New York, Chicago, and Los Angeles) and many receiving sites (the number of cable television systems participating). In the cable-television-distribution-only design a lower performance (and, therefore lower cost, perhaps 5 K$ to 10 K$ in quantity) receiver is desirable since there are so many in the system. In the general common carrier system, there are relatively few receivers (normally) so a properly designed system would have higher performance receivers which cost more, perhaps 50 K$ to 100 K$. At present there is not enough unity of interest in satellite distribution within the cable television industry to finance either approach.

Although high start-up costs and lack of video material of wide interest has dampened the interest of the cable industry in satellite usage, there have been hardware demonstrations. TelePrompTer Corporation has sponsored recent evaluation tests using Anik I and Anik II satellites at 4.0 and 6.0 GHz. A transportable receiving station has been on tour across the United States since the first transcontinental delivery of domestic satellite television programs was presented to a public audience at the annual National Cable Television Association (NCTA) conference on June 18, 1973.

This demonstration, along with the Communications Technology Satellite (CTS) experiments at 11.95 and 14.15 GHz, illustrate the capability of present technology.

Satellite distribution would provide a nationwide network for cable television programming of general interest which is independent of local broadcasters. As such, it would indicate a certain independence and maturity of the cable industry. However, there are large start up costs. Launch and hardware costs of a synchronous communications satellite are over 10 million dollars. Considering the financial picture of the cable industry, such a financial commitment in the near future seems unlikely.

Even if the financial picture indicated that a cable television satellite distribution was viable, the question of national interest must be raised. Communication satellites, as well as terrestrial microwave communications, use the crowded microwave spectrum. The question of a limited spectrum is immediately raised, as well as another unexpected but limited resource in increasing demand, namely the synchronous orbit required by the satellite. Is it even desirable to have a synchronous communications satellite distributing six channels of general interest programming material?

It should be noted that the distribution of network programs has little direct impact on cable television practice. A satellite network is an additional source of programs, and, if of interest to potential subscribers, will increase penetration and enhance the economic viability of the industry (assuming increased revenues overcome the hardware costs). However, there is no impact on the role of the cable television industry within the wider communications community, as was described in the section on regional cable system design and as will be discussed in the section on intersystem point-to-point design.

In summary, the technology for providing nationwide distribution of video programming by a communications satellite in synchronous orbit is available. However, the large start-up costs, as well as recurring costs of generating appropriate programming material, does not indicate that such an endeavor is viable at present. The effect of such a project on the use of two limited resources, spectrum space and synchronous orbits, should be considered in more detail before further hardware studies are performed.

2.8.4 Intersystem Point-to-Point

With intersystem point-to-point interconnection, any cable television head could communicate with any other cable television headend. This interconnect capability, combined with regional cable systems as described previously, would have a dramatic effect on cable television practice. Long distance, high speed data transmission service could be provided at low cost for the business community, a service which is in demand at present.

We assume that cable television networks would provide the local loop and the specialized common carriers (MCI, Datran, Western Union, etc.) would provide the long distance interconnect. That is, the cable television local or regional network would compete with the telephone company in providing local connection, while the specialized common carriers compete with AT and T Long Lines. Presently, specialized common carriers negotiate with the telephone company for local loop service. If cable television networks penetrate into urban areas and these networks are capable of providing point-to-point communication service, cable television could move more toward common carrier status and a wider role in telecommunications.

It should be emphasized that this scenario is a long range projection in the 1990 time frame. It presupposes a local (or preferably regional) cable television network capable of point-to-point communication service. These systems are beginning to be designed, with the Mitrix system by Mitre Corporation already demonstrating a limited form of point-to-point communication. Although more efforts are needed, we anticipate that cable television systems providing point-to-point service will be demonstrated in the field in the latter 1970's.

The orderly development of specialized common carriers is considered to be a necessary step toward the development of intersystem point-to-point capability. Although specialized common carriers and regional cable systems providing non-entertainment services are likely to develop independently for the next 5 - 10 years, we anticipate that they will eventually combine their distribution capabilities to provide intersystem point-to-point capability. Lack of technical standardization, as well as regulatory constraints, could inhibit this evolution.

REFERENCES

2-1. "1972-73 CATV Systems Directory, Map Service and Handbook," Communications Publishing Corporation.

2-2. "R. L. Smith, "The Wired Nation," Special Issue of The Nation, 210, 582-606 (1970).

2-3. E. B. Parker, "Democracy and Information Processing," Educom, 5, 2 (1970).

2-4. Committee on Telecommunications, National Academy of Engineering, "Communications Technology for Urban Improvement," Report to the Department of Housing and Urban Development under Contract No. H-1221, June 1971.

2-5. Urban Cable Systems, MITRE Corporation Report M72-57, May 1972, Table II-2 and Figure II-4, pages II-9 and II-20.

2-6. W. S. Baer, "Interactive Television - Prospects for Two-Way Services on Cable," Rand Report R-888-MF, November 1971.

2-7. J. E. Ward, "Present and Probable CATV/Broadband-Communication Technology," Report ESL-R-449, prepared for the Sloan Commission on Cable Communications, 7 June 1971 (revised 5 January 1972).

2-8. R. K. Jurgen, "Two-Way Applications for Cable Television Systems in the '70's," IEEE Spectrum 8, 39 (1971).

2-9. Jerrold CATV Product Catalog, 1972.

2-10. A. S. Taylor and L. H. Janes, "Field Testing the Performance of a Cable TV System," Proc. IEEE 58, 1086 (1970).

2-11. L. L. Johnson, et al., "Cable Communications in the Dayton Miami Valley: Basic Report," Rand Report R-943 KF/FF, January 1972.

2-12. W. A. Rheinfelder, "CATV System Engineering," Second Edition, TAB Books, Thurmont, Maryland, 1967.

2-13. K. Simons, "Technical Handbook for CATV Systems," Third Edition Jerrold Electronics Corporation, Hatboro, Pennsylvania, 1968.

2-14. R. W. Lucky, IEEE International Convention Digest, 442 (1967).

2-15. President's Telecommunications Task Force, R. S. Powers, Chmn., "The Wired City: 1980," Institute for Basic Standards, National Bureau of Standards, Boulder, Colorado (June 1968).

2-16. "The Picturephone System," Special Issue of the Bell System Technical Journal, 50, 219-709 (February 1971).

2-17. E. M. Dickson and R. Bowers, "The Video Telephone," Report NSF-RA-S-73-004, Cornell University, June 1973.

2-18. B. M. Oliver, J. R. Pierce, and C. E. Shannon, "The Philosophy of PCM," Proc. IRE 36, 1324 (1948).

2-19. D. Kirk and M. J. Paolini, "A Digital Video System for the CATV Industry," Proc. IEEE, 58, 1026 (1970).

2-20. J. Martin", Systems Analysis for Data Transmission", Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1972, p. 202.

2-21. S. T. Levine, "Focus on Modems and Multiplexes," Electronic Design 22, (1974).

2-22. J. Martin, Op. cit. p. 168.

2-23. A. B. Carlson,"Communication Systems," McGraw-Hill, New York, 1968, p. 315.

2-24. R. H. Franklin and H. B. Law, "Trends in Digital Communication by Wire," IEEE Spectrum 3, 52 (1966).

2-25. G. C. Hartley, P. Mornet, F. Ralph, and D. J. Tarran, "Techniques of Pulse-Code Modulation in Communication Networks," Cambridge University Press, London, 1967, p. 63.

2-26. H. Rubin, "Data Transmission: A Direction for Future Development," IEEE Spectrum 7, 79 (1970).

2-27. R. P. Gabriel, "Dial A Program -- An HF Remote Selection Cable Television System,' Proc. IEEE 58, 1016 (1970).

2-28. R. P. Gabriel, "Wired Broadcasting in Great Britain," IEEE Spectrum 4, 97 (1967).

2-29. J. P. Thompson, "The Optimum Cable Telecommunications System," 20th Annual National Cable Television Association Conference, Washington, D.C. (1971).

2-30. K. Rose and R. K. Stevens. "Design of a Switched Broad-Band Communications Network for Interactive Services," IEEE Trans. on Communications COM-23, 49 (1975).

2-31. A. Feiner and W. S. Hayward, "No. 1 ESS Switching Network Plan," BSTJ, 43, No. 5. pt. 2, p. 2214 (1964).

2-32. "Switching Systems," American Telephone and Telegraph Co., 1961.

2-33. D.G. Fink, "Principles of Television Engineering," McGraw-Hill, New York, 1940, pp. 30-31.

2-34. [illegible]. K. Tate, "Microreproduction," The Encyclopedia of Photography, Greystone Press, New York, 1963, p. 2285.

2-35. J. Volk, "The Reston, Virginia Test of the MITRE Corporation's Interactive Television System," Report MTP-352, The MITRE Corporation, May 1971.

2-36. ROBOT Voice Band Television Equipment, Robot Research, Inc., San Diego, California.

2-37. E. M. Dickson with R. Bowers, "The Video Telephone," Report NSF-PA-N-73-004, Cornell University, June 1973.

2-38. Reference Data for Radio Engineers, Second Edition, Howard W. Sams and Co., Inc. Indianapolis, Indiana, 1968, pp. 30-39.

2-39. Tektronix Products, 1974 Catalog; Tektronix Inc., Beaverton, Oregon.

2-40. 1975 Southwest Technical Products Corporation Catalog, 219 W. Rhapsody, San Antonio, Texas.

2-41. W. S. Baer, op. cit., p. 34.

2-42. H. [illegible]. O'Neill, "A Technology Assessment Methodology, Volume 3, Computers-Communication Networks," NTIS Report PB-202 778-3, MITRE Corporation, McLean, Virginia (1971).

2-43. J. R. Millar, R. J. Gutmann, and K. Rose, "Methods for Supplying Interactive Services on Broad-Band Communication Networks," IEEE Trans. On Communications, COM-23, 73 (1975).

2-44. R. C. Dickinson, "Commercial Data Communication Over a Cable Television System," Nat. Community Television Assn. Digest 22, 203 (1973).

2-45. D. G. Willard, "A Time Division Multiple Access System for Digital Communication," Computer Design 13, 79 (1974).

2-46. "MITRE's Interface Adapts CATV to Digital Terminals," Electronics 46, 29 (1973).

2-47. "Signal Communications, Military," Encyclopedia Britannica, 20, 498 (1968).

2-48. A. A. Bergh and P. J. Dean, "Light Emitting Diodes," Proc. IEEE 60, 156 (1972).

2-49 J. Stone and C. A. Burrus, "End Pumped Fused Silica Neodymium Doped Fiber Geometry Lasers Operating at 1.06 and 1.08 μm Wavelength," Appl. Phys. Letters 23, 388 (1973).

2-50. K. C. Kao and T. W. Davies, "Spectraphotometric Studies of Ultra-Low Loss Optical Glass," J. Sci. Instr. 1, Series 2, 1063 (1968).

2-51. W. B. Bielawski, "Low Loss Optical Waveguides: Current Status," Electro-Optical Systems Design, 5, 22 (1973).

2-52. W. A. Gambling, et. al., "Gigahertz Bandwidths in Multimode, Liquid Optical Fiber Waveguide," Opt. Commun. 6, 317 (1972).

2-53. "New High Efficiency Light Fiber Brings Laser Communications Closer," Bell Laboratories News Release (May 31, 1973).

2-54. A. D. Pearson, et. al., "Preparation of a Light Focusing Glass Rod by Ion-Exchange Techniques," Appl. Phys. Lett. 15, 76 (1969).

2-55. Electronic News, p. 25 (April 9, 1975).

2-56. C. A. Burrus, et. al., "Pulse Dispersion and Refractive Index Profiles of Some Low Loss Multimode Optical Fibers," Proc. IEEE 61, 1498 (1973).

2-57. P. Witherell and M. E. Faulhaler, "The Silicon Solar Cell as a Photometric Detector," Appl. Opt. 9, No. 1 (Jan. 1970).

2-58. S. K. Ghandhi, "The Theory and Practice of Microelectronics," J. Wiley and Sons, Inc., New York, 1968, Chapter 10.

2-59. News Item, Electronic Design, 24, 258 (1973).

2-60. Data Sheet, Avantek Inc., Santa Clara, California (1972).

2-61. Data Sheet, Microwave Semiconductor Corp., Somerset, N. J. (1972).

2-62. J. E. Fulenwider, "Current and Emerging Opportunities in Optical Communications," Talk Given to NSF Grantee-Users on Optical Communications, George Washington University, St. Louis, Mo. (Nov. 14, 1973).

2-63. T. Alexander, "Lots of Talk, Not Enough Fax," Fortune, p. 122 (February, 1973).

2-64. "Reading," Encyclopedia Americana.

2-65. K. Owen "For the Record" Rensselaer Polytechnic Institute, May 1974.

2-66. "Cable Television: Options for Jacksonville," Cable Television Information Center, the Urban Institute, 1972.

2-67. L. L. Stine, C. M. Plummer, and M. A. Lambert, "Local Distribution of Telecommunications - a Perspective," MITRE Report M71-91, August 1971.

2-68. T. S. Eller, "Terminal Device for Interactive Television Systems and their Impact on Services," IEEE International Convention (Session 4), March 1974.

2-69. Report on Cable Television by Cabinet Committee chaired by Clay T. Whitehead, 1974.

2-70. "Meeting the Challenge of Cable Telecommunications," MITRE.

2-71. R. V. C. Dickinson, "Commercial Data Communications Over a Cable Television System," 1973 NCTA Symposium Digest, pp. 203-210, June 1973.

2-72. Q. B. McClannan and G. P. Heckert, "A Satellite System for CATV," Proc. IEEE, 58, pp. 987-1001 (1970).

3. ECONOMIC AND REGULATORY CONSIDERATIONS

3.1 Overview

This section is primarily a review of current studies of cable television economics and regulation. Economic and regulatory aspects are closely linked because most federal regulation to date has been concerned with the economic impact of cable television on the communications industry.

A foundational economic analysis of CATV systems was carried out by W. S. Comanor and B. M. Mitchell in their paper, "Cable Television and the Impact of Regulation."[3-1] They were concerned about the prospective economic effect on cable television of proposed FCC regulations which would require, among other provisions, that some steps be taken to develop BCN capabilities. In particular, 20 channel capacity, some two-way capability, 21 hours/day of program origination, and additional channels for local cablecasting were proposed. Comanor and Mitchell were concerned to estimate "the impact of these regulations on the structure of costs and demand, and thereby, on prospective profitability for typical CATV systems."

Section 3.2 reviews the Comanor-Mitchell analysis and uses it as a basis for discussing cable television economics. Basic factors in an economic analysis are demand, cost, and revenue. Sections 3.2.1 and 3.2.6 review estimates of demand and revenue, respectively. In Section 3.2.1 it is shown that estimates of demand for conventional cable television are subject to considerable uncertainty. The demand for additional cable service cannot be established by analyzing current cable television usage. The most useful estimate of economic feasibility is a measure such as Internal Rate of Return which considers the time value of money. Such calculations are reviewed in Section 3.2.6, where it is shown that a simple relationship between capital investment and internal rate of return cannot be derived.

The remaining portions of Section 3.2 are concerned with system costs. A more detailed analysis is possible here. The Comanor-Mitchell paper[3-1] provides detailed cost estimates and financial projections for conventional cable television systems. These are reviewed in Section 3.2.2. Because the distribution system is by far the largest capital cost, its costs are considered in more detail in Section 3.2.3. This analysis of conventional distribution system costs is then used as a basis for comparing the costs of FDM and SDM distribution systems in Section 3.2.4. Our analysis uses a distribution system design program developed by us for this project. Details of the computer program are given in Appendix A. The capital costs of higher performance levels (as described in Section 2.3) are estimated in Section 3.2.5.

Section 3.3, Regulatory Considerations, is in two parts. The first part reviews the history of cable television regulation up to about 1970. This review indicates that federal regulation has been based largely on the economic impact cable television would have on competing communications media. Cable television has been subject to a complex patchwork of federal, state, and local regulation. Particular emphasis has been placed upon the terms of the New York City franchise, since it most clearly reflects a concern for the evolution of a broadband communications network. Particular emphasis is also placed on proposals for regulation by New York State, since New York State defined its position in terms of public interest.

With this as background, present and future prospects for cable television regulation are then summarized. This summary reflects a current concern about over-regulation. Present regulations may be placing so many requirements for public services on the cable television industry that its economic survival is threatened. Policy alternatives are suggested which might ease the financial burden on cable television operators of providing a wide range of public services.

3.2 Economic Considerations

3.2.1 Demand Estimates for Conventional Systems

Comanor and Mitchell considered an individual's demand curve for television channels, assuming all channels are equivalent. (This curve is shown as the decline in the price per channel, P, as a function of the number of channels, N.) They regard the demand for CATV as really a demand for additional television channels. "Since individuals can generally receive some number of channels over the air without paying any fee, the demand for television channels via cable can be derived by subtracting the number of free channels received from the general demand curve for television."

Strictly speaking, broadcast channels are not free since the consumer must invest in a television set and reception equipment (i.e., an antenna and its cable) to receive them. The cost of terminals needs to be included in a complete economic analysis of broadband communication networks because it is a large fraction of the cost per subscriber of the total system. This is particularly true of systems supplying interactive services where more expensive terminals may be required to minimize the cost of the distribution system.

It should be emphasized that the Comanor-Mitchell analysis only considers the demand for additional conventional television channels. (This corresponds to a Level 1 or 2 system as discussed in Section 2.3.) No estimates were made of the demand for or increase in revenues from interactive services. Such estimates are necessarily very much more speculative and are discussed further in Chapter 5.

Comanor and Mitchell derive a set of demand equations from a random sample of 149 CATV systems drawn from a total population of 2490 systems listed in the 1970-71 Television Factbook.[3-2] The dependent variable was taken as penetration, the ratio of subscribers to the number of homes passed by television cable. Several factors were considered as independent variables. The main factor was the number of additional channels which a cable subscriber can receive. More exactly, the variable was the ratio of the number of channels of a specific type carried by cable to the number broadcast of the same type. Four types of channels, stations, or program schedules were distinguished on the basis of consumer acceptance:

primary network stations, independent stations, duplicate network stations, and noncommercial (generally public or educational) stations. Automated and live Local Origination (Level 2 of Section 2.3) were considered as separate variables. Monthly charge, family income, and system age were additional variables considered.

Of all of the variables, only the number of additional primary network stations and the age of the system were statistically significant factors.* (A 100 percent increase in the ratio of 'one plus the number of stations carried via cable' to 'one plus the number of stations which can be received over the air' would be associated with a 25 percent increase in the subscription rate.) The penetration level should increase rapidly at the start, exceeding 80 percent after 4 years and be virtually complete after 10 years. Although below the level of statistical significance, results indicated that additional noncommercial stations have little impact on the number of subscribers but automated and live local origination have negative and positive impacts respectively on the number of subscribers. An additional variable was tested which indicated whether the system was within the top 100 markets. Although not statistically significant, the tendency was toward *lower* subscription rates in the top 100 markets if everything else were identical.

This analysis of demand was improved by Park who noted that previous analyses were based only on data from the Television Factbook. Thus, they did not consider broadcast reception difficulties which would tend to bias households toward cable television. He felt that a more valid analysis would be based on the penetration of cable television in areas without reception difficulties. Accordingly, he analyzed a carefully selected group of 63 systems whose freedom from reception difficulties and system data were confirmed by telephone conversations.

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*The form of these variables seems to have been chosen in accord with certain expectations of the system performance. For the additional channel variable, the marginal impact of additional channels declines as the number of channels expands. The form of the age variable was chosen "to assure that the system could rapidly approach maturity."

As in Comanor-Mitchell, subscriber penetration was used as a measure of demand. This was taken as a product of ultimate penetration and system maturity. (The form of the ultimate penetration function was chosen to lie between zero and one for any range of variables. Variables were added logarithmically to reflect the basic assumption that equal proportionate changes would have equal effects on the ultimate penetration. The maturity factor was assumed to depend exponentially on the age of the system. Maturity factor = exp $(-\alpha/A)$ where A = system age and α is a parameter to be estimated by the regression analysis.) The independent variables analyzed were television service, subscription price, household income, and the fraction of households with color television. Five categories of television service variables were considered corresponding to different types of stations: primary network, duplicate network, independent, noncommercial (educational), or Canadian. The service variables were written in a form which depended on the numbers of broadcast and cablecast stations of a particular type, and the distance of the stations from the cable system. UHF broadcast stations were given a lower weight because UHF reception tends to be poorer than VHF reception.

A careful analysis of statistical significance was made. This established that "UHF broadcasting," "the number of primary network stations distributed," and "household income" were significant at the 1 percent level. "Distance from stations" was significant at the 1 to 5 percent level, depending on the form of the distance relation. "Duplicate network stations," "Canadian stations," and "subscription price" were significant at the 5 percent level. There was a negative correlation with "subscription price" and, surprisingly, "distribution of Canadian stations." What was particularly surprising was that the age of the system was not a significant factor in penetration. This suggests that penetration was essentially complete in a much shorter time than had previously been assumed. Penetration was found to be about unit elastic with respect to both price and income. Thus, a one percent decrease in subscription price would increase penetration by about one percent, having about the same effect as a one percent increase in subscriber income.

In many respects these statistical analyses of the demand for cable television confirm conventional wisdom. People are much more interested in network programs than any others and are primarily interested in good reception of present programs. This is not surprising, since network programs are monitored and marketed for maximum viewer acceptance. The demand for additional cable services (e.g., Level 2 services) appears to be marginal. It cannot be established by analyzing present CATV usage. An alternative approach is considered in Chapter 5.

3.2.2. Cost Estimates for Conventional Systems

Perhaps the most useful feature of the Comanor-Mitchell article is their detailed analysis of the cost structure of a CATV system.

Since no comprehensive cost statistics are available for this industry their estimates were based on data provided by independent consultants and CATV operators. For all major cost components an attempt was made to gather several independent estimates. They found that many cost factors were well established but others varied considerably. Costs were divided into operating and capital costs and then into major components of cost for the CATV operator. Their estimates for a system of 7500 subscribers outside the top 100 markets is shown below in Table 3.1. Other systems were considered, but this system was most thoroughly analyzed. Comparative data for other system sizes is shown in Table 3.2. Headend Costs are shown separately as well as included in Capital Costs.

Table 3.1 1970 costs for a Cable Television System of 7500 Subscribers Outside the Top 100 Markets. (All estimates are undiscounted totals for a ten year assumed life of plant.)

Capital Expenses	(%)	
Headend	4.5	
Distribution System	64.5	
Drops	27.0	
Inventory, Tools, Furnishings	4.1	
TOTAL	100.	1130K$
Operating Expenses	(%)	
Salaries	46.7	
Maintenance	10.5	
Pole Rental	12.9	
Office	18.7	
Advertising and Promotion	3.2	
Taxes	8.3	
TOTAL	100.	2000K$

Table 3.2 1970 Costs per Subscriber for Cable Television Systems (All estimates are undiscounted totals for a ten year assumed life of plant.)

Cost in $/Subscriber

Number of Subscribers	Capital	(Headend)	Operating	TOTAL
(Outside Top 100 Markets)				
3500	140	10	320	460
7500	150	7	270	420
(In Top 100 Markets)				
3500	150	13	330	480
7500	140	6	250	390
25000	140	2	220	360

From Table 3.1 we see that over a ten-year period, about 1/3 of the total system costs are capital investment. Of these capital costs almost 2/3 are in the distribution system. The distribution system as defined here includes only the trunk and feeder cables. If house drops are included, the cost of the distribution system is about 90 percent of the total investment. From Table 3.2 we see that the capital costs per subscriber are nearly independent of system size, but there appear to be some economies of scale with respect to operating costs.

Actually the constancy of distribution costs in $ per subscriber masks a substantial drop in headend costs per subscriber as shown in Table 3.2. The 140$ "investment" of each subscriber in the distribution system should be contrasted with his 100 to 500 $ investment in a television receiver. (This cost is based on his initial purchase price and, for equivalence, assumes that the television set lasts ten years and requires no maintenance.) Alternatively, an investment of 10$/subscriber in a 10,000 subscriber system would allow an investment of 100 K$ in headend equipment. This is certainly enough to purchase a powerful computer at today's prices.

This analysis of capital costs raises the contrast between investments in terminals and investments in the headend or distribution system as alternative methods of supplying subscriber services. This is an Economic Issue which is closely allied with the Technical Issue of performance tradeoffs discussed in Section 2.5. As the relative costs indicate, it costs less to modify the headend than the distribution system. Thus, the tradeoff between headend and distribution system modifications to supply subscriber services is an important Economic Issue. This is closely allied with the Technical Issues involved in chosing a multiplexing method which were discussed in Section 2.4.3.

In Section 2.3 we indicated stages by which a cable television network might develop into a broadband communications network. Examining these stages it appears that, with the exception of program origination, implementing them requires increased expenditure on headend equipment, terminal equipment, or the distribution network rather than increased operating expenses. Thus, we will generally assume that additional operating costs can be neglected when estimating the costs of developing broadband communication networks.

3.2.3 Distribution System Costs

We need to examine distribution costs in more detail because they represent such a large fraction of capital investments. Comanor and Mitchell (1970) estimated that the trunk and feeder cable network would cost 4 K$/mile above ground (aerial) and 15 K$/mile underground. They report the results of several studies, all of which give values ranging from 3.7 to 4.5 K$/mile for above-ground distribution. The range for underground distribution is much greater. It ranges from 6.5 K$/mile for cable in sand to 75 to 100 K$/mile for cable under the streets of New York City. Douglas Jardine, Inc. (1970) made a detailed estimate of 13.3 K$/mile for construction of an underground distribution network in Colorado Springs, Colorado. From this we see that construction is the major fraction of distribution system cost.

Pole arrangement (which we have included in above ground distribution costs) was estimated to cost 750$/mile in the top 100 markets and 300$/mile outside the top 100 markets. House drops (which we have listed separately) were estimated to cost 20$/subscriber above ground and 35$/subscriber underground.

A more detailed cost analysis was made by Feldman for a proposed Dayton Metropolitan Area cable system of advanced design.[3-4] "The system assumed for the base case is a more ambitious undertaking than any now in operation (1972): a two-cable system with a capacity of 40 to 50 video channels from the headend to subscribers, plus a return capacity of two or three video channels... In addition to a central studio for program origination, five local sector studios and three mobile units are provided."[3-5] Feldman's estimate for aerial cable installation are shown below in Table 3.3.

Table 3.3 Estimated Investment Costs of Above-Ground Cable Installation (Table 1-6, Reference 3-4, 1972).

Single 12-channel Cable	4500	$/mile
Increasing Capacity of Single Cable to 20-25 Channels	500	
Simultaneous Installation of a Second 12-Channel Cable	1500	
Increasing Capacity of Second Cable to 20-25 Channels	500	
Adding Two-Way Capability to One Cable	800	
Tree Trimming and Pole Preparation	700	
TOTAL	8500	$/mile

These estimates are close to the 1970 Comanor-Mitchell estimates (4000 + 750) $ for a comparable system. Note that the capacity of the system can be raised from 12 channels to 40 or 50 channels for an investment of 2 K$. This amounts to a four-fold increase in channel capacity for a 30 percent increase in cost. Three video channels of return capability are provided for a 10 percent increase in cost.

We have made independent estimates of the cost of a conventional FDM distribution system for an urbanized area of 240 single family houses. Each house was on a 75' x 150' lot in 300' x 750' blocks of 20 houses. Since cable television lines most commonly are attached to telephone poles we assumed that telephone poles were spaced 100' apart and a 4-way tap serving 4 houses was attached to each pole.

This data was used in a computer program developed at Rensselaer as a part of this project. The program automatically designs FDM and SDM distribution networks for a symmetric, repetitive, rectangular grid structure of lots, blocks, and streets.[3-6] Our design program is intermediate in complexity between the fixed cost per mile assumption of Comanor-Mitchell and Feldman and the detailed package of automated FDM design programs developed by Frisch and associates of the Network Analysis Corporation (NAC).[3-7,3-8] *

Unlike previous simulations, the purpose of our design program was to allow detailed comparison of FDM with SDM broadband cable communication

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*Given only the distribution of subscriber locations, corresponding to the street layout of a particular community, the NAC programs detail the layout of feeder and trunk cable, the location and specification of subscriber taps, and the location of distribution amplifiers. The optimization of the design arises primarily from their allowing the computer to analyze many alternative layouts and hardware combinations before choosing the design which minimizes cost and yet still meets the specifications. Such a scheme would naturally attempt to utilize peculiarities of the subscriber grid to good advantage.

technologies. Thus, our automated design will lay out the design of either an FDM or SDM cable system given a set of design rules and a catalog of available components. A simple scalable topography (rectangular grid) was assumed to simplify the design procedure. NAC claims that their more complete design automation can produce cost savings of about 20% in components over "hand calculated" designs. Since construction costs are a much larger fraction of distribution costs, a more elaborate design procedure did not seem worthwhile. A more detailed description of our program is given in Appendix A.

3.2.4 Comparison of FDM and SDM Distribution Costs

A high-capacity, single-trunk, single-feeder FDM distribution system was computer designed for a 3 x 4 block neighborhood serving 240 subscribers. They system had a downstream capacity of 20 to 24 video channels and a (sub-split) upstream bandwidth of 25 MHz. Assuming 100% penetration, the total cost was 87 $/subscriber. If subscriber converter units were added to allow full utilization of the system's 24 channel capacity, the cost would rise to about 120 $/subscriber.

The component costs for this analysis are summarized in Table 3.4. Hardware costs are taken from the 1973 Jerrold Catalog;[3-9] installation costs are based on independent consultation with cable television industry personnel in the Spring of 1973. The pole preparation charge is a 50 $/pole average fee to New York Telephone. (New York Telephone's 1973 pole rental fee is 5 $/year.) A more detailed breakdown of costs is given in "The Wired Campus--A Design for the Rensselaer Community".[3-10] This is the final report of a class design project under the direction of Professor Gutmann and was affiliated with our study.

Table 3.4 1973 Cost Components for Subsplit Single Cable FDM Distribution System (Reference 3-9)

Trunk and Feeder Cable	1080	$/mile
Amplifiers and Taps	2150	
Cable and Hardware Installation	2910	
Pole Preparation	1920	
TOTAL COST	8060	$/mile

Comparing our estimates with Feldman's estimate in Table 3.3, our costs are 6140 $/mile compared with Feldman's 5800 $/mile for comparable systems, neglecting pole preparation charges. This is reasonable agreement considering the differences in time and location for which the estimates were prepared. (The Rand projection[3-5] estimated an average of 110 households/mile corresponding to a cost of 77 $/subscriber for 100 percent penetration.)

A 36 channel SDM distribution system was computer designed using one local exchange for the same 3 x 4 block, 240 subscriber neighborhood. The total cost was 272 $/subscriber, assuming 100% penetration. The system was designed with an extra video cable (twisted wire pair) for each subscriber although only one was connected initially. This would allow two-way video or an extra video outlet to be installed at a later time without modifying the distribution network. If the extra video cable were not included, the cost would drop to 255 $/subscriber.

Hardware costs were taken from literature and information supplied by Rediffusion International Ltd. in Spring 1973. (Rediffusion is virtually the only manufacturer of video switching systems for mass distribution.) Labor costs were assumed to be the same for installing SDM and FDM cable; local exchange installation costs were supplied by Rediffusion. A more detailed cost breakdown in given in Reference 3-10. Our estimated cost of 255 \$/subscriber agrees with the 256 \$/subscriber estimate in 1971 of J. E. Ward for a 36-channel Rediffusion system.[3-11] (The agreement is closer than one should expect since somewhat different sssumptions were made in the two analyses.)

Our computer program allows one to estimate the influence of household density on system cost. The household density for the above neighborhood corresponds to 7.2×10^{-5} households/ft^2 or 3.1 households/acre. Alternatively, it may be expressed as 100 households per mile of trunk and feeder cable or 128 households per street mile. This is in reasonable agreement with the average housing density of 110 homes per mile in the Dayton-Miami Valley area.[3-12] Our computed designs show that FDM distribution system costs vary from 132 \$/subscriber for 1.3 subscribers/acre to 70 \$/subscriber for 413 subscribers/acre. A comparable variation was found for SDM distribution systems.

Housing densities can vary significantly. Commanor and Mitchell[3-1] used densities of 120, 100, and 80 households per mile for core cities, outlying communities in major markets, and other markets. The core city values are probably low. For example, the city of Dayton has a housing density of 147 households/mile.[3-12]

Comparing FDM and SDM distribution systems, we see that a basic 24 channel FDM system costs 120 $/subscriber while a basic 36 channel SDM system costs 255 $/subscriber. Thus, it appears that 50% more channels have been made available for twice the cost. The basic FDM system would appear to be the better bargain. One would expect that SDM systems might have a cost advantage for high bandwidth consumption services. One such service is a subscriber-accessed Video Library which requires the use of a video channel by a single subscriber for a substantial time. We estimate that Video Library service would tie up about one FDM channel for 200 subscribers or 10 channels for 2000 subscribers. (This assumes ideal dynamic allocation of channels and that 80% of the requests are completed. The background for this estimate is given in Chapter 5.) To supply additional channels beyond the capacity of a single FDM coaxial cable, more cables must be laid paralleling existing cables. Thus, to retrofit by adding an additional cable the cost of the entire distribution network must be duplicated. This is a cost investment comparable to the cost of the initial plant and would tend to inhibit the development of high bandwidth consumption services on FDM distribution systems.

As discussed in Section 2.4.4 individualized services are provided in an SDM distribution system by installing additional crosspoint switches in the local and central exchanges. Our computerized design program automatically calculates the number of switches required to meet a given demand. For Video Library service as described above one needs 12 crosspoints/subscriber. For crosspoint switches costing 3 $ this amounts to 36 $/subscriber. To control this system, integrated curcuits would need to be installed in local exchanges and a minicomputer would need to be installed in the central exchange. Stevens estimated that the additional control equipment would cost 40 $/subscriber in 1972.[3-13] This would probably be lower in 1974 as a result of advances in integrated circuit technology. This amounts in total to an additional cost of about 76 $/subscriber to provide Video Library services. Additional control equipment of comparable cost would have to be provided for the dynamic allocation of FDM channels. Even so, FDM distribution systems would still appear to have a cost advantage for bandwidth intensive individualized services such as a Video Library. The advantage decreases as the number of subscribers served by a single FDM distribution network increases.

3.2.5 Cost of Higher Performance Levels

We defined a hierarchy of performance levels for cable television technology in Section 2.3. In this section we will estimate the additional cost of reaching higher performance levels. The cost of Level 1 (Conventional Cablecast) has already been discussed.

Level 2 (Local Origination):

Automated information systems (time/weather, news wire, stock ticker) cost about 10 K$.[3-14] Facilities for live programming can vary considerably in cost. Baer and Park[3-5] estimate capital equipment costs of 210 K$ for one master station and 25 K$ for one mobile station in their "austere origination" projection for Metropolitan Dayton. They estimate

49 K$ a year in operating expenses divided equally between two master station personnel and two mobile studio personnel. Producing live television is expensive. Oregon State University profides 1300 hours of cable television programming a year at a cost of 170 K$ for equipment and 70 K$/year for maintenance staff.[3-15] Sesame Street cost 24 K$ per hour of program in its first year.[3-16]

Level 3 (Terminal Attachments):

Per subscriber costs are in the ballpark of 25 $ for pay TV attachments which permit subscribers to receive programs on otherwise restricted channels.[3-17]

Level 4 (Data Return):

Per subscriber costs for relatively sophisticated typewriter keyboard and buffered video display terminals have been estimated at 500 $.[3-18] More modest two-way data terminals comparable to Touch-tone telephone sets should begin at 50 $/subscriber.[3-19] Additional information on the cost of data terminals is given in Section 2.5.1.

Level 5 (Addressed Message):

Costs here depend on the extent to which channels are automatically allocated to individual subscribers on a dynamic basis. Equipment must be provided to split video channels into subchannels and control the reception of those channels by particular subscribers. Both FDM and TDM would need to be used for high efficiency channel splitting. We estimate costs of roughly 100 $/channel. Dynamic allocation control costs would be comparable to those estimated for SDM systems or roughly 30 $/subscriber.

Level 6 (Processed Message):

Once addressed message services are implemented, the additional computer hardware costs for routine calculations are likely to be small. For a 2000 subscriber system, 10 $/subscriber would add considerable computer hardware. The software required for what would be a 2000 terminal time-shared system is likely to be more expensive.

Level 7 (Video Return):

Provided sufficient upstream channel capacity is available, the minimum cost for video return to the headend is a 200 - 250 $ video camera.

Level 8 (Point-to-Point):

Once Addressed Message and Video Return capabilities are established, Point-to-Point communications can be inaugurated. Additional costs depend on demand. Even moderate traffic would require significant expansion of distribution capacity. This would require additional bandwidth for FDM systems or additional crosspoint switches for SDM systems as discussed in Section 3.2.4.

3.2.6 Financial Projections for Cable Television Systems

So far, we have not taken the time value of money into consideration. Both Comanor-Mitchell and the Rand study of the Dayton-Miami Valley area used computer simulations to determine the cash flow and internal rate of return for investment in a cable television system.

To this point, we have only estimated the capital and operating costs of a cable television system. Before one can complete a financial analysis, revenues must be estimated as well. Traditionally, the bulk of cable television revenues have been monthly rental payments by subscribers. Additional revenue has come from advertising in some systems.

The 1970 Seiden Report estimated a possible advertising return of 8736 $/year for a thousand subscriber system. This assumes the system sells 16 one minute spots during the four hours of prime time every day of the year and charges 1.5 $/thousand subscribers for each minute. This is an optimistic estimate of advertising revenue. Even so, it is small compared with the 60 K$/year of subscriber rents in a thousand subscriber system.

Subscriber rents have tended to remain constant. This probably results from the difficulty of renegotiating local franchises, federal regulation, and competition among firms for franchises. The Seiden Report noted that most recently franchised systems charged between 5 and 7 $/month. Comanor and Mitchell[3-1] assumed 5 $/month/subscriber in their simulation. The Rand report[3-5] considered several investment alternatives but considered 6 $/month/subscriber as the monthly subscriber fee for their base case. Even in 1975 the monthly subscriber fee has remained at 6 \$/month/subscriber for the several cable systems serving the metropolitan Albany area. Since monthly subscriber fees are relatively inelastic, the income derived by cable television owners is a critical function of penetration rates.

The 1970 Comanor-Mitchell projection for a 7500 subscriber cable television system outside the top hundred markets is summarized in Table 3.5. The distribution network had 151 miles of cable of which 5% was assumed to be underground. Depreciation was determined on a straightline basis for an assumed ten-year life of the capital equipment. It was assumed that half of the total could be raised by borrowing at 10 percent per annum. Corporate income tax was calculated assuming that the firm consisted of a single cable system.

Table 3.5 shows that major capital expenditures occur immediately while revenues build up relatively slowly. The internal rate of return (IRR) is calculated to be 5.3%. This assumes the system would have to be substantially rebuilt after 10 years. The internal rates of return are 8.8 and 11.6% for 12 and 15 year lives, respectively.

Several other factors can affect the IRR and system profitability. One is the household density which Comanor-Mitchell assumed to be 80 homes per mile. Higher densities or higher penetrations would make the system more profitable. Park's study[3-3] indicated a more rapid rise of subscriptions to the final penetration level. This would also increase profitability. Finally, lower interest rates or higher monthly subscriber fees would increase system profitability.

The Rand study[3-5] contains similar financial projections for twelve variants of cable systems for Metropolitan Dayton. It used the Comanor-Mitchell

Table 3.5 Financial Projections for a 7500 Subscriber Cable Television System Outside the Top Hundred Markets[3-1]

Year	1	2	3	4	5	6	7	8	9	10	Total
%Penetration	16	29	45	52	56	58	60	61	61	62	62
Subscribers	1930	3480	5410	6340	6800	7040	7270	7350	7420	7500	7500
Capital Expenditures (K$)											
Headend and Tower	48										48
Distribution Network	730										730
Drops	40	45	58	39	29	23	22	17	16	16	304
Inventory	49										49
Operating Expenditures (K$)											
Salaries	54	68	81	88	102	108	108	108	108	108	933
Maintenance	7	7	7	10	10	10	13	13	13	13	103
Pole Rental	26	26	26	26	26	26	26	26	26	26	260
Office and Misc.	27	36	47	47	51	53	53	54	55	55	474
Promotion	19	9	4	4	4	4	4	4	4	4	65
Local Taxes	10	12	17	17	18	18	19	19	19	19	166
Sources of Funds (K$)											
Revenue Collected	60	167	275	363	406	428	442	452	456	461	3510
Beginning Cash Balance		25	25	25	25	25	25	35	227	398	810
Equity	536										536
Loans	439	80	17								536
Use of Funds (K$)											
Capital Expenditures	867	45	58	39	29	23	22	17	16	16	1122
Operating Expenditures	143	158	181	192	211	219	223	224	225	225	2001
Interest		44	52	54	46	34	18	2			250
Income Taxes									45	52	97
Loan Retirement				78	120	152	168	17			535
Cash Balance	25	25	25	25	25	25	35	227	398	566	1376
Net Income	-170	-126	-56	-16	45	69	92	116	75	70	132

computer program to make calculations. However it assumed a more rapid growth of penetration, reaching 80% of the final level by the end of the second year. The Base Case system is a two-cable FDM distribution system with 40 to 50 downstream video channels and two or three upstream channels. The final penetration was assumed to be 40% of all homes passed and the monthly subscriber fee was set at 6 $/month. Extensive local origination facilities (one central studio, five local sector studios, and three mobile units) are included. The effect of system variations on the internal rate of return is summarized in Table 3.6. Internal rate of return is calculated assuming the system is sold after ten years at ten times the annual operating income.

The return to total investment includes the return to both equity and debt investors. Two-thirds of the capital was assumed to be borrowed at 10 percent interest in calculating the return to equity capital alone. The leverage involved increases profits or, as in Case 3, losses for the equity investors. Case 2 indicates the effect of leverage. Cases 3 and 4 indicate the effect of changes in penetration. Cases 9 through 12 indicate the effect of changes in subscriber density and system size. These factors are summarized in Table 3.7.

Lowering the subscriber fee to 4 $ (Case 6) lowers the rate of return to an unattractive level. Alternatively, revenue from channel leasing (Case 7) could be used to lower the subscriber fee to 4.25 $/month while retaining the total internal rate of return at 14%. However, this assumes a very ambitious channel leasing program. It assumes that 10 channels are leased to educational users at 35 K$/year per channel and another channel is leased to a pay-TV movie operator at 350 K$/year. On the other hand, austere local program origination (Case 8) could

Table 3.6 Internal Rates of Return[3-5]

CASE		IRR (%) Total	IRR (%) Equity
1.	The base case	14	17
2.	One-to-one debt-equity ratio	14	15.4
3.	Thirty percent cable penetration	3.1	-18.2
4.	Fifty percent cable penetration	20.9	26.0
5.	Use of converters instead of dual cable	12.3	14.3
6.	4$ subscription fee	6.5	1.2
7.	Additional revenue from channel leasing	19.0	23.8
8.	Austere local program origination	16.7	20.8
9.	Only incorporated cities	11.3	12.4
10.	Only Dayton	20.4	26.2
11.	Only Kettering	12.6	15.1
12.	Only Fairborn	-100	-100

Table 3.7 Population Distribution in Metropolitan Dayton

City	Population (thousands)	Housing Density (Homes/Mile)
Metropolitan Area	426	110
Dayton	244	149
Kettering	70	110
Fairborn	32	107

be used to lower the subscriber fee to 5 $/month.

The capital cost per subscriber is 268 $ for the Base Case. Increased performance levels can be related to increases in capital cost per subscriber, as shown in Section 3.2.5. It would be desirable to develop a relationship between the internal rate of return and the capital cost per subscriber. Such a relationship would provide some measure of the financial feasibility of improved cable television performance. Unfortunately, it is not possible to establish such a relationship on the basis of the results in Table 3.6.

Consideration of Case 5 illustrates some of the difficulties in determining such a relationship. In Case 5, frequency converters were used with a single cable to provide the high channel capacity of the dual cable Base Case. This reduced capital investment in frequency converters for each subscriber. It was estimated that this would reduce the operating cost of maintaining the distribution system but would double the number of service calls by the average subscriber. Overall, as shown in Table 3.8, the capital costs decreased, operating costs increased, and revenues remained constant. The net result was a significant drop in the internal rate of return. From this we see that the influence of capital investment on IRR is complexly affected by the magnitude and timing of associated operating expenses. Table 3.6 provides no instance in which the effect of capital investment can be isolated.

Table 3.8 Financial Comparison of Cable Systems

	Base Case	Converters
Subscribers (thousands)	84.3	84.3
Capital Expenditures (M$)	22.5	21.7
Operating Expenditures (M$)	36.7	39.4
Revenues (M$)	57.4	57.4
Operating Income (M$) (Year 10)	3.3	2.8
Internal Rate of Return (%)	14	12.3

3.3 Regulatory Considerations

3.3.1 History

The regulatory status of cable television before 1970 has been summarized in an article by E. S. Smith.[3-21] As he points out, cable television has offered the promise of new and improved communications services. Its emergence has also induced "fears for the economic security of various broadcast, theater, copyright, and manufacturing interests." The corresponding legal disputes and conflicting business interests have formed the background for government (FCC) policy.

Smith contents that "the two principal forces affecting the evolution of CATV have been: (1) the uncompromising demand of the public for a greater diversity of program sources than the broadcast industry has provided, and (2) the competitively motivated opposition to CATV of the broadcast industry." Since Smith has served for several years as Special Counsel to the National Community Television Association, Inc. (NCTA), he may reasonably be assumed to represent the cable television industry's view of the regulatory situation.

Since CATV was initiated in small communities with poor broadcast reception, "initial opposition came from small-town broadcasters operating in marginal markets."[3-21] Thus, in 1954, about five years after the first CATV system was constructed, the licensee of Television Station WJPB-TV at Fairmount, W. Va., filed the first CATV related petition with the FCC. In April 1959, the FCC released a Report and Order in its CATV inquiry indicating that it was probable that CATV had an adverse economic effect on television stations but that it could not conclude that CATV had been a material factor in the demise of any station. Moreover, it "found nothing which would justify us in taking action, or seeking authority under which we could act, to bar CATV's from coming into or continuing to operate in a particular market."[3-22] That is, the FCC felt it lacked jurisdiction over CATV systems but recommended to Congress that the Communications Act be amended to require CATV systems to obtain permission from originating broadcasters to receive their signals.

In 1962, however, the FCC denied an application by a CATV system operator to construct a common carrier microwave relay system for the importation of distant signals.[3-23] The application had been protested by a small-town broadcaster on the ground that the economic impact of the microwave-fed CATV system would adversely affect the public interest. Smith notes that this decision was made even though the hearing examiner had found no factual evidence of economic impact which was of probative value. Smith discusses this decision under the heading, "The Carter Mountain Case--The Beginning of the FCC Drive for Control of CATV."

In 1965 the FCC issued a "Notice of Inquiry and Notice of Proposed Rule Making (Docket 15971)"[3-24] proposing to make its Business and Common Carrier Microwave Rules applicable to all CATV, and inquiring into several areas for possible additional rules. Smith presents evidence that this notice was the result of increasing concern by major market television broadcasters represented by the National Association of Broadcasters (NAB).

At the same time, controversy over copyright infringement by CATV operators was proceeding through the courts. In 1966 the U. S. District Court for the Southern District of New York delivered its decision that

CATV systems infringed copyrights by publicly performing copyrighted programs. This decision was reversed by the U. S. Supreme Court in 1968. Although some ambiguities remained, Smith[3-21] notes that it was "generally accepted as confirming the (CATV) industry's traditional position that in functioning as a master antenna service it does not infringe copyrights." It should be noted that since movie reruns are the staple fare of most cable television systems, the MPAA (Motion Picture Association of America) and the NAB have copyright interests.

To some extent Cable television has always been tied to the telephone industry. Cable television systems have attached their cables to telephone and power utility poles. Pole preparation fees and pole rentals constitute significant fractions of the capital and operating expenses of cable television companies. According to Smith,[3-21] "the telephone industry did attempt to protect itself from possible competition by strict prohibitions against any kind of communication over the CATV cable except transmission of broadcast signals over the air." In the early to mid-sixties independent telephone companies sought to enter the cable television industry by construction or purchase of operating systems. The Bell system and major independents filed tariffs with a number of state commissions requesting the right to rent channels to CATV operators. CATV operators became apprehensive that telephone companies would use their control of the conditions for pole use to take over CATV systems. To resolve this issue the FCC adopted a Final Report and Order[3-25] in 1970 which prohibited telephone companies from furnishing CATV distribution facilities directly or through an affiliate within their operating territory. At present, most telephone companies have relaxed or deleted CATV communication restrictions from their attachment agreements.

Cable television systems have also been regulated locally through municipal franchises. These franchises are based on the power of municipalities to control access to public streets and thoroughfares within their boundaries. As might be expected, considerable variation exists. Commissioner Jones reviewed the situation in New York State for the Public Service Commission.[3-26] General franchise provisions are listed in Table 3.9.

In 1970 New York City awarded long term contracts to two cable companies which are among the most sophisticated attempts at effective municipal regulation. The provisions for additional channels are of particular interest. At the outset the franchisee is required to transmit 17 channels to subscribers: 11 channels for local signals, one Company Channel, two Public Channels, two City Channels, and one Additional Service Channel. Company Channels are reserved for cablecasting program material originated by the cable operator or another person in accordance with FCC regulations. Public Channels are reserved for program material provided by persons leasing channel time and, if necessary, studio facilities from the cable operator. City Channels are reserved for use by the city. Additional Service Channels are reserved for other communications services provided by the cable operator. Priority on use of Additional Service Channels is to be given to persons other than the cable operator.

Table 3.9 Municipal Franchise Provisions[3-26]

1. Term of franchise
2. Franchise exclusivity
3. Franchise fees
4. Rates to subscribers
5. Prohibition against discrimination
6. Free services and facilities
7. Schedules for construction and operation
8. Construction and maintenance requirements
9. Programming standards
10. Technical service standards
11. Innovation allowances
12. Business restrictions
13. Franchise transfer or abandonment
14. Report and inspection requirements
15. Insurance and indemnification
16. Performance bonds and right of cancellation
17. Superseding regulation
18. System status on termination of franchise

The Jones report[3-26] is particularly concerned with whether state regulation of cable television is in the public interest and if so the form such regulation should take. Not suprisingly, the accompanying letter of the Chairman of the New York State Public Service Commission to Governor Rockefeller concludes that it is.[3-27] In making his case for state regulation, Chairman Swidler reviews his view of the scope of federal and municipal regulation. "Federal regulation of CATV has focused primarily on the programming practices of CATV systems. The FCC has been concerned mainly about protection of television broadcasting stations, both commercial and educational, from fragmentation and diversion of their audiences." Swidler then reviews the scope of municipal franchises and comments that "in some matters they are particularly unsatisfactory, because they are unflexible or unenforceable or both. In other respects, existing franchise terms reflect an appropriate balancing of public and private interests in securing for the community both revenues and services from CATV operations."

Swidler suggests that the state Public Service Commission should set minimum standards of technical, financial, and character fitness as well as construction and operation. PSC approval of municipal franchises would be required to assure conformity with these standards. Swidler envisions that "the PSC would occupy a middle position between the municipalities and the federal government. On the one hand, it would set general standards for, and provide advisory services and technical sources to, municipalities engaged in granting or seeking to enforce a CATV franchise. On the other hand, it would represent the

State's interest in proceedings before the FCC to assure that federal regulation would be designed to permit the CATV interest of the State to develop and expand along lines consistent with the long-run public interest."

Swidler later elaborates his view of the "long-run public interest." "Finally, the measures proposed will assure that CATV subscribers are adequately protected; that the development of New York's CATV industry will produce a Statewide system capable of interconnection and compatible with the developing state of the art; that the public interest will be protected against undue concentration of control of mass media in New York State; and that access to this new medium will be provided to all users on equitable terms--in particular, those seeking to employ CATV channels for public and educational purposes."

3.3.2 Present and Future Prospects

Final rules of the FCC regarding cable television service went into effect in the Spring of 1972.[3-28] Development of cable service in major cities had heretofore "been blocked by interim regulations that effectively prohibited the importation of distant television signals."[3-29] Mitchell and Smiley[3-29] summarize these rules as follows. The final rules permit limited importation, varying with the size of the market and the variety of broadcasters already present. The rules require 20 channels downstream transmission capacity and a potential for upstream transmission from the subscriber to the headend. Additional rules include an FCC fee of 0.30$/subscriber, technical standards and a required annual performance certification. Three access channels for government, educational, and public use are specifically mandated. The first two are to be provided free on a five-year trial basis. The system must have one or more channels available for leasing, and must expand them when demand increases. Fianlly the FCC has suggested that three to five percent of gross revenues are appropriate upper limits for local franchise fees and that higher fees require a showing of cause to the Commission.

Of particular note is the omission of required compensation to copyright owners for the programs carried. This issue has been left to the courts and Congress. Cable systems currently pay copyright fees for movies and other material shown on their local origination channels and must purchase rights to the programming carried on pay or leased channels. However, cable systems currently obtain the bulk of their video material without a payment to either the stations or the copyright holders of their programs.

Mitchell and Smiley[3-29] have modified the Comanor-Mitchell analysis to consider the impact of the new FCC regulations on the profitability of cable systems. They assume a more rapid rate of penetration growth, consistent with Park's analysis.[3-3] They conclude that "except where atypical conditions prevail, cable systems will be unprofitable in central urban areas having good broadcast reception, but marginally profitable on the edges of larger cities. In these latter cases rates of return are not far above the estimated cost of capital. However, copyright fees of the magnitude that have been proposed are likely to deter cable construction in many of these areas." Further they conclude, on the basis of Park's analysis, that higher subscriber fees would cause a large enough drop on the number of subscribers to cancel any increase in revenue.

These conclusions have been challenged by Crandall and Fray[3-30] who conclude that "the potential for revenue of cable television is greatly underestimated if attention is focused solely upon importations of broadcast signals and low-quality local originations. Cable television opens up the possibility for a price-rationed system of entertainment in the home pay TV which far surpasses the current television medium." "One needs only to assume that pay cable will allow systems to attract 50 percent of the homes passed by the cable and that revenues per subscriber will increase at a rate of 2 percent per year to obtain this more sanguine result [rates of return on investment on prospective investment consistently above the cost of capital.]" (They criticize the Comanor-Mitchell estimates of operating costs for overestimating the economics of scale and criticize their estimates of capital costs because they laid all cable in the first year and put too much underground.) It is interesting to note that the research of Mitchell and coworkers was financed by the National Cable Television Association while that of Crandall and Fray was financed by the Motion Picture Association of America.

To this point, cable television has been regulated primarily on the basis of its economic impact on other industries in the entertainment communications industry. The principal issue of litigation has shifted from the importation of additional stations to copyright payments. FCC regulations have tended to bias cable operations toward both cablecasting and common carrier activities. Cablecasting is a natural consequence of providing facilities for the local origination of programming. Common carrier activities are encouraged by requiring channel leasing and provision for upstream communication. Whether these activities will prosper remains an open question.

Anne Branscomb, a communications lawyer and former counsel for a major cable television operator, Teleprompter, concludes that "Science fiction claims and 'blue sky' promises oversold the industry and tied it up in red tape."[3-31] She concludes that "the cable industry is beset with a cautious investment community, an overzealous triumvirate of government regulators, an honest infusion of self-doubt, and a pessimistic public."

Considering the economic aspects, Branscomb contends that at current interest rates "cable operators simply cannot afford to borrow money to build new systems unless they are in marginal television reception areas where the profitability and immediate return on investment is assured." A token commitment to program origination has been dropped as as economy move, cablecasters concluding that program origination was losing money and gaining few viewers. "The industry is now relying upon pay cable as the way to salvation... there is no evidence at the moment that the cable industry will produce the imaginative cable services promised by the cable dreamers." On the other hand, she believes that satellite distribution technology should soon be able to interconnect up to 80 channels to all cable systems at a modest cost. She finds it particularly ironic that "the crisis in financial capability has come at a time when technical capability is almost within grasp." Thus, it appears that economic constraints are likely to inhibit if not preclude the development of BCNs.

Considering the regulatory aspects, Branscomb criticizes the FCC rules as saddling "a new technology with too much public responsibility in its infancy before it has had time to develop the economic base necessary to sustain such public commitments." Remembering the history of communications regulation, she recalls that "each successive [communications] technology has been the repository of these hopes [for public service] and has failed them." She is particularly critical of the three state cable commissions. "On the contrary [compared with Massachusetts], the New York Cable Commission looks upon itself as a promoter of cable development; to the extent that it pursues this goal diligently, it may, in fact prove highly catalytic in helping to encourage intrastate connections, providing legal and technical expertise which individual small operators cannot afford. However, New York [State] is an ill-conceived geographic unit to encourage the kind of regional interconnection which would be optimum. The New York [City] metropolitan area should logically coordinate its telecommunications planning and development with New Jersey and Connecticut, not with New York State."

Branscomb does not feel that technology is a major problem. The problem is economic. She also feels that the blue-sky visions of the cable enthusiasts could and perhaps should be realized by the utilization or modernization of the existing telephone system. Thus, she proposes that policy-makers should reassess some of their current axioms. In particular, she proposes a five point program summarized below:

1. "Cable should be encouraged to develop in partnership with and not as competitor to existing technologies--broadcasting and telephone companies... The sooner policy-makers recognize the interrelatedness and interdependence of the various components of our communications system, the more workable and sensible the solutions to existing problems will become."

2. "Prohibitions against investment of one technology in another should be abandoned."

3. "Ownership of the hardware should not result in control of the content."

4. "Regulation of the hardware should be by a national standard, but regulation which affects people's political and sociological habits should be regulated by those units of government which have familiarity with the political and social consequences of regulation. Regulation at all levels should concentrate on the positive rather than the negative aspects of telecommunications development--on technical compatibility, quality of signal deliverance, diversity of access to the maximum number of users. Above all, the regulatory process should not be used as a device for inhibiting growth potential by competing technologies... The optimum boundaries of the information utilities of the future may bear no logical relationship to the political boundaries of today."

5. "If the public wants to participate in the message, then the public, or publics, whoever they may be, must be willing to pay the price in time, energy, and allocation of financial resources... A new telecommunications system can hardly succeed financially on a piecemeal basis, since the more imaginative uses require substantially full penetration--and the costs are staggering."

REFERENCES

3-1 W. S. Comanor and B. M. Mitchell, "Cable Television and the Impact of Regulation," The Bell Journal of Economics and Management Science, 2, 154 (1971).

3-2 Television Digest Inc. "Television Factbook," Washington, DC: Television Digest Inc., semiannual (1970-71).

3-3 R. E. Park, "Prospects for Cable in the 100 Largest Television Markets," The Bell Journal of Economics and Management Science, 3, 130 (1972).

3-4 N. E. Feldman, "System Designs for the Dayton Metropolitan Area," in Cable Communications in the Dayton Miami Valley: Basic Report, Report R-943KF/FF, RAND Corporation, Santa Monica, California, January 1972.

3-5 W. S. Baer and R. E. Park, "Financial Projections for the Dayton Metropolitan Area," Ibid.

3-6 L. A. Cogansparger, "A computer Simulation of Broadband Cable Communications System Design: Part A - Distribution," M. E. Thesis, Rensselaer Polytechnic Institute (May 1974).

3-7 I. T. Frisch, B. Rothfarb, and A. Kershenbaum, "A Computer Design of CATV Distribution Systems," Cablecasting, 7, 20 (July-August 1971).

3-8 H. Frank and I. T. Frisch, "The Design of Large-Scale Networks," Proc. IEEE, 60, 6 (1972).

3-9 CATV Systems Catalog, Jerrold Electronics Corporation, Horsham, Pennsylvania, 1973.

3-10 "The Wired Campus - A Design for the Rensselaer Community," R. J. Gutmann, Ed., Report TRC-101, Telecommunications Research Center, Rensselaer Polytechnic Institute (August 1973).

3-11 J. E. Ward, "Present and Probable CATV/Broadband-Communication Technology," Report ESI-R-449, Sloan Commission on Cable Communications, January 1972.

3-12 W. S. Baer and R. E. Park, op. cit., p. 2-12.

3-13 R. K. Stevens, "Design of a Switched Broadband Cable System for New Communities," Ph. D. Thesis, Rensselaer Polytechnic Institute (October 1972).

3-14 "Automated Information Systems Appear on Cable TV Scene at Propitious Time," Broadcast Management Engineering, 10, p. CM/E14, November 1974.

3-15 L. L. Johnson, "Cable Television and Higher Education: Two Contrasting Experiences," Report R-828-MF, RAND Corporation, Santa Monica, California, September 1971.

3-16 D. D. Connell, "How Sesame Street Raised and Spent Eight Million Dollars," Dividend, Graduate School of Business Administration, University of Michigan, Ann Arbor, Winter 1971.

3-17 "What We Now Know About Pay Cable; Part II, Equipment," Broadcast Management Engineering, 10, p. CM/E18, July 1974.

3-18 "MITRE's Interface Adapts CATV to Digital Terminals," Electronics, 46, 29 (1973).

3-19 "NCTA 1974: Confrontation with Reality," Broadcast Management Engineering, 10, p. CM /E18, June 1974.

3-20 M. H. Seiden and Associates, CATV Report, 1970.

3-21 E. S. Smith, "The Emergence of CATV: A Look at the Evolution of a Revolution," Proc. IEEE, 58, 967 (1970).

3-22 26 F.C.C. 403 (1959).

3-23 Carter Mountain Transmission Corp., 32 F.C.C. 459 (1962).

3-24 30 Fed. Reg. 6078 (1965).

3-25 21 F.C.C. 2d 307 (1970).

3-26 W. K. Jones, "Regulation of Cable Television by the State of New York," State of New York Public Services Commission, December 1970.

3-27 J. C. Swidler, Chairman State of New York Public Service Commission, letter to Governor Rockefeller (31 December 1970).

3-28 U. S. Federal Communications Commission, "Cable Television Service: Cable Television Relay Service," Federal Register, 37, No. 30, Part II, pp. 3252-3341 (12 February 1972).

3-29 B. M. Mitchell and R. H. Smiley, "Cable, Cities, and Copyrights," The Bell Journal of Economics and Management Science, 5, 235 (1974).

3-30 R. W. Crandall and L. L. Fray, "A Reexamination of the Prophecy of Doom for Cable Television," The Bell Journal of Economics and Management Science, 5, 264 (1974).

3-31 A. W. Branscomb, "The Cable Fable: Will it Come True?", Journal of Communication, 25, 44 (1975).

4. IMPACT ON SOCIETY

4.1 Overview

This chapter considers the impact of broadband cable communications on society. Of the many areas of concern, the social, political and economic are perhaps the most important. Each of these in itself is very complex, and deserving of a complete study in its own right. A number of previous studies have considered specific facets of this problem. We will present an overview of these other studies and follow by describing the possible impact of cable television on specific service areas.

In the course of this study, we soon discovered two problems which have a dominant influence on our approach. The first problem was that we are in a period not only of rapid change but, more important, rapid multiplication of communications technology possibilities. This meant that it is especially dangerous to isolate a particular factor for study since it could soon be eliminated or transformed by competing or complementary technologies. The second problem was that changes in modes of communication can radically change society. In fact, a case has been made for regarding communications as the basis of society.*

Although both of these problems are extremely important, a comprehensive attack on either of them was clearly beyond the financial and organizational resources of this study. In our work, we have deliberately taken an approach which would emphasize those issues for which we could support our recommendations by technical information and engineering analysis. Thus, we have confined our impact analysis to brief reviews of the impact cable television could have in providing a wide range of social services.

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*Three well known but significantly different presentations of this hypothesis are McLuhan's "The Gutenberg Galaxy", Duncan's "Communication and Social Order", and Meier's "A Communications Theory of Urban Growth".

Each review suggests impacts and summarizes pertinent knowledge in the field. In most cases, not enough is known to permit a reliable estimate of social impact.

A more complete analysis is presented of the impact of cable television on education since we already had considerable experience in education. Our analysis has been published in the Special Issue on Social Implications of Telecommunications in the IEEE Transaction[illegible] Communications.[4-1] Even here, we have confined ourselves to the immediate impact and have not speculated about secondary and tertiary impacts.

It is certainly possible for cable communication networks to provide services in the areas of entertainment, information, education, consumer aids, business, health, public services, and individual communications. Of first importance is the fact that all of these needs can be satisfied without telecommunications. For example, one can watch live actors in a stage play for entertainment or listen to a lecture by a teacher in a classroom for education. The extent to which telecommunications will be used to supply these needs will ultimately depend on the cost, convenience, and quality of the service. At present, for example, most of us watch more television programs than stage plays for entertainment although we still rely heavily on the classroom teacher for education. A second example is the area of mail delivery. Here, facsimile transmission could replace the transportation of letters.

A significant study is the National Academy of Engineering report entitled, "Communication Technology for Urban Improvement."[4-2] Their study was conducted by a panel of distinguished experts in the field of telecommunications. As such it represents the views of engineers rather than social scientists regarding the impact of technology. Nonetheless, it does reflect informed opinion on the possibilities and limitations for expanded use of telecommunications services. The report considered the areas of impact outlined in Table 4.1.

TABLE 4.1. Areas of Impact - The NAE Study

Citizen Government Interaction

Education

Health Services

Pollution Control and Monitoring

Transportation

Crime Prevention and Emergency Services

Another study, "The Video Telephone" by E. M. Dickson and R. Bowers,[4-3] is particularly pertinent because it represents a technology competing with cable television to provide similar services. Today, the telephone can be considered as a narrow-band interactive medium, as opposed to cable television which is broadband, but essentially non-interactive. Thus, there is the ever-present issue of whether particular services should be provided by making the telephone broadband, or by making cable television interactive.

The areas of impact considered in this study are listed in Table 4.2.

TABLE 4.2. Areas of Impact - The Videophone Study

1. Human Response to Video Telephones
2. The Structure and Location of Organizations
3. Substitution of Communication for Transportation
4. Video Telephones, Energy Utilization, and the Environment
5. Video Telephones and the Deaf
6. Medical Applications and Impacts
7. Impacts in Education
8. Some Economic Considerations
9. Legal and Regulatory Issues
10. International Consequences

Two more recent references which summarize current studies are the January and October 1975 special issues of the IEEE Transactions on Communications. These were devoted to Interactive Broad-Band Cable Systems and Social Implications of Telecommunications, respectively.

4.2 Service Areas

We now consider, separately, a number of services which can be provided by cable technology. Next, we show the capability which can be provided by each of these functions, and discuss its possible impact on society.

4.2.1 Entertainment

We are beginning with this category because it is familiar from our experience as consumers of television and radio. It will be convenient to analyze entertainment services in terms of the extent to which the programs are individualized for each consumer. Thus, we will talk about present-day mass media or macromedia, micromedia, and duomedia. Each of these modes is explained below.

Macromedia: This is the type of mass media represented by commercial television. In the present system, local television broadcasters are affiliated with national networks which provide programs for national distribution. Since the costs of programs are borne by advertisers seeking mass markets rather than by individual consumers, the variety of programs is severely restricted. Since broadcasting stations in larger cities, such as New York City, reach significantly larger local markets, a larger number of channels and a correspondingly wider variety of programs are possible.

A significant increase in the variety of available channels could be provided by using a community antenna to receive distant broadcasts and a cable television system for distribution. By way of example, Capital District (Albany, Schenectady, Troy, New York) residents could have the same choice of programs as residents of New York City, Boston, or Montreal. Costs of tying in to these outlying metropolitan areas could be included in the subscription costs of a cable system.

Micromedia: This is a type of mass media designed to serve a particular group of consumers or a particular community. The availability of a large number of relatively inexpensive channels would permit two significant innovations in television usage.

In the first place, programs could be developed on a national basis to serve the particular interests of minority groups - sports enthusiasts, youth, Roman Catholics, blacks, Puerto Ricans and other Spanish speaking groups, musicians, etc. These groups represent the interests of significant number of people. Since mass television must necessarily focus its attention on the interests of the majority of its viewers, it is able to accommodate minority interests only sporadically - or not at all. At present, these interests are met by specialized magazines, newspapers, or foreign language radio stations in the larger metropolitan areas. If a sufficiently large national market existed, and many channels could be provided by cable television, such programs could be brought to a much larger and more dispersed population. In addition, a much wider diversity of entertainment would be made available to any consumer.

A second, but equally important, innovation would be the possibility of providing television programs designed for a particular community or local geographical area. This type of programming is probably less important in the area of entertainment than it is in other areas such as information and education which we will consider later.

Monomedia: The logical extension of the micromedia concept is monomedia, television entertainment designed to provide the viewers with what they want to see, whenever they want to see it. In general, this should be technically feasible provided a sufficient variety of programs are available, facilities exist for storing and retrieving these programs, and computer facilities are provided for automatically sequencing the viewer's choices.

It should be possible for the system to provide schedules which are the equivalent of a menu or shopping list from which the viewer could select those programs which particularly interested him. Such schedules could be prepared on the basis of interests previously tabulated by the viewer. Although more use is made of telecommunications technology, the process involved in monomedia is quite similar to that of selecting a book at a public library.

Duomedia: The selection of programs by responding to a schedule or menu prepared by some component of the telecommunications network involves a two-way interchange mediated by the telecommunications system. We have called this Duomedia. Television or radio shows in which selected viewers are called or in which the commentator responds to telephone calls are quite popular and provide other examples of Duomedia. In all of these examples, sufficient interaction can be provided by an audio return link. Sometimes, however, it might be desirable to provide a video return link, as has been done in televised interviews.

4.2.2 Information

At present, the citizen is informed about the state of his world, nation, state, and community by a wide variety of media: television news broadcasts, radio, magazines, newspapers, and town meetings. While some areas may be covered more extensively than others, the quality and quantity of public information has been criticized at all levels of government. When considering possible ways in which telecommunications systems could improve the quality of our information services it will be helpful, once again, to consider the roles that macromedia, micromedia, monomedia, and duomedia might play.

Macromedia: Relatively little needs to be said here since this is probably our major source of information at present. However, as in the case of entertainment, additional channels which provided the viewer with the diversity of news services available to residents of New York City, Boston, or Montreal would seem to be a definite advantage.

Micromedia: Locally generated news and information broadcasts could be of great help as a supplement to community meetings. Regularly scheduled programs on local issues could be used to result in a better informed community. The use of telecommunication media could allow community issues to be considered in greater depth and detail, and resolved on an integrated, long-term basis rather than in response to particular issues.

Information could also be provided on meetings and events of community interest such as service clubs, church suppers, and school announcements. Inexpensive telecommunication media would also allow local candidates for public office to have a wider exposure to the electorate. All of these uses of a community television network could foster a sense of community identity and spirit.

Monomedia: Monomedia would allow particular viewers to focus in greater depth on issues of special interest to them. For example, in a fully developed telecommunication information system, this would allow the viewer to make an in-depth examination of ecology and conservation practices or school funds at national, state, and local levels. As such information systems become available they might be introduced in the educational system where they would magnify the information resources available to each student.

Duomedia: The effect of duomedia on government could be quite significant. On the one hand, it would allow polls or opinion surveys to be conducted economically and efficiently on local, state, and national issues. On the other hand, it would allow the people to be heard in the video equivalent of town meetings. This would be particularly advantageous to older citizens, since their participation is often limited by a lack of transportation. With some creative thought this could become a potent tool for citizen participation in the solution of community problems.

One such system, called MINERVA, has been proposed by the Center for Policy Research, New York City and Washington, D.C.[4-4] Two "Electronic Town Meetings" were conducted during the fall of 1972 and spring of 1973 by the MINERVA group.[4-5] Both meetings were tenants' meetings held in apartment complexes of one to two thousand apartments. In both meetings a panel of tenants spoke first. While this was going on, persons who wished to present views went to a central location in their building where their remarks were videotaped. Following a response to the videotaped comments by the panel a vote was called and participants were requested to fill out questionnaires on their reactions to the meeting. Half to two-thirds of the participants preferred the electronic format to face-to-face meetings. The overwhelming majority reported that the electronic meeting had increased their desire to do something about the issues discussed.

4.2.3 Education

We particularly addressed ourselves to the impact of cable television on education since we had expertise in education as a social service. Our analysis has been published in the Special Issue on Social Implications of Telecommunications in the IEEE Transactions on Communications.[4-5]

To evaluate the impact of cable television on education we addressed a series of questions. Is there some innate superiority of classroom teaching which a broad-band communications system could never provide? That is, what would the impact of cable television be on the quality of instruction? Is the necessary technology available? Does this technology cost too much? Would a larger market appreciably lower cost? Would televised instruction be popular? That is, what is the "Individual Preference" for educational telecommunications? Would widespread use of instructional television require revolutionary changes in our present educational system? Would our educational institutions allow that to happen? Can they prevent it? That is, what is the "Institutional Resistance" to educational telecommunications?

To analyze the effect of more sophisticated cable technology on education we have used the concept of Performance Levels discussed in Section 2.3 of this report.

4.2.3.1 Education as a Social Service

The high degree of overlap between education, information, and entertainment requires a more narrowly focused definition of education as a social service. Does Sesame Street provide entertainment, information, or education? Can one separate these functions? For example, to what extent could one divide a particular program into distinct time segments corresponding to education, information, and entertainment? Educators are painfully aware of the fact that children in an urban environment are more likely to remember the top twenty songs than the twenty most populous countries.

We suggest that the distinctive feature of education is certification. Put crassly, Sesame Street is not educational if one does not receive academic credit for watching it, but it is education if one watches it in a classroom under the supervision of a licensed teacher. Most of the questions raised earlier about the impact of televised instruction on education are related to the question of certification. More specifically, the impact of broad-band communications on education depends directly on whether one can get a diploma or equivalency certificate.

The same issue is raised in an alternative way by considering the extent to which television watching can be incorporated into the classroom. Incorporating television into the classroom avoids the issue of certifying work done outside the classroom. Since it is compatible with present educational procedures it is less disruptive to the educational system than developing an alternative to classroom education.

At the same time, this approach cannot increase educational productivity unless it is coupled with larger classes or lower paid supervision. (One cannot lower costs by increasing the cost of capital investment as a factor, i.e., buying a television set, unless the cost of labor is reduced as a factor.)

4.2.3.2 Quality of Televised Instruction

The first question to be answered is whether there is some innate superiority of classroom teaching which a broad-band communications system could never provide. It is helpful to rephrase this question by asking whether a broad-band communications system can provide more than a classroom teacher could provide in a particular teaching situation. In principle, the answer is no. Anything transmitted over a broad-band telecommunications system can be no more than the televised version of some live performance. In practice, there are advantages and disadvantages of a televised performance.

The main disadvantages of instructional television are the limitations set by the system's performance level. Two limitations of key importance are limited feedback and lack of resolution.

In the lecture or demonstration mode of education a skilled classroom teacher habitually adjusts his presentation to the response of his audience. The smaller the class the more easily this is done, and our own experience suggests that this is not readily accomplished for audiences of more than thirty. That is, it is almost always accomplished for audiences of 10, but generally not accomplished with audiences of 100.

At this point, the perspectives of the technologist and teacher tend to diverge. From the perspective of the teacher, the simplest and most natural form of feedback is to observe the audience. This would require a Level 7 system with video return. Educational technologists have tended to favor a data response system (Level 4) where, for example, lights flash when students press buttons. Such systems have not found widespread acceptance even after significant marketing efforts by major corporations in the 1960's. They tended to be little used and less reliable. The reliability of much educational technology is well described by Oettinger.[4-6] The cost of a Level 7 system rises in proportion to the amount and frequency of its use. It is conceivable that remote monitoring could replace direct observation, but one would have to overcome significant barriers of cost and custom.

In both recitation and self-paced modes of education, feedback is essential for all class sizes. Feedback in these modes requires the students to answer questions. One limit of this mode is programmed instruction, where the student can only proceed by answering questions; the other is the final or comprehensive examination. It is important to realize that testing can be accommodated on broad-band communications systems at several different performance levels. In the first place, a broad-band communications system is not necessary. Programmed textbooks, correspondence schools, and English universities have traditionally relied upon various forms of this mode to educate without benefit of broad-band communications. Televised lectures have often been supplemented by distributing examination papers either in the classroom or by mail. To perform this operation electronically would require at least a Level 4 (Data Return) or Level 6 (Processed Message) system. At Level 4 data would be returned to a person for evaluation; at Level 6 they would be returned to a computer. At Level 6 the broad-band communication system functions as a computer communications link. Similar service could be provided using the telephone network as the computer communications link. At this level, Oettinger's book[4-6] gives useful insights into the prospects for educational innovation. Once again, the most economical method corresponds to a delicate balance of costs which could significantly shift in particular situations. Our own cost estimates suggest that once message addressing (Level 5) is implemented the hardware costs involved in implementing Level 6 are small. Programming costs would be comparable in any event.

Finally, televised instruction is degraded by the limited bandwidth of a video channel. This limits the resolution of a conventional 14" diagonal 525 line television receiver to 52 scan lines/inc. A similar degradation of resolution occurs when movies are shown on television. The resolution of 16 mm film is comparable to that of conventional television. In contrast, the resolution of a typed page is 200 scan lines/in and that of a printed page is 300 scan lines/in. This means that conventional television is a much poorer display medium than an ordinary blackboard or overhead projector. Even doubling the resolution (and bandwidth) of a televised display would not provide the resolution or capacity (number of characters displayed) one is accustomed to in conventional documents or books. This severely restricts the form of classroom presentations, although some educators have argued that the quality of technical instruction is improved if the size of mathematical formulas is reduced.

So far, we have discussed the capabilities of televised education in terms of educational methods. Are there unique advantages or disadvantages of televised education in terms of educational areas. P. Carpenter's excellent report "Cable television: Uses in education"[4-7] indicates that "television has been shown to be very useful in teaching facts, concepts and cognitive skills ... it is also useful in demonstrating motor and psychomotor skills and, to the extent that demonstration is sufficient for instruction, can carry the burden of instruction even in some performance areas." The effectiveness of television advertising suggests that television may be effective in shaping attitudes on a superficial level. Fortunately, major shifts in attitudes such as the term brainwashing implies appear to be much harder to bring about.[4-8]

In other words, television has been demonstrated to be effective in teaching a wide variety of subjects to a wide variety of student populations.[4-9] To cite a particular instance, student achievement resulting from extensive use of a closed circuit television system in Maryland's Washington County public school was carefully measured.[4-10] The data indicate that, on the whole, students tended to learn more from video instruction in basic skills than they did from conventional classroom instruction. In addition, the system allowed instruction in special subjects such as science and mathematics which were beyond the scope of the regular curriculum.

It seems that the necessary hardware either is or could be made available. Provided appropriate changes are made in teaching methods, the limited resolution of conventional television receivers still permits effective education.

4.2.3.3 Technological Factors

The major advantage of cable television over broadcast television is the greater number of channels it can supply. Even so, the channels required to transmit a complete university or school curriculum would exceed the available capacities or conventional cable systems. An estimate of channel requirements can be made by equating channels to classrooms. Rensselaer, with a somewhat restricted curriculum, uses 81 classrooms with 70 percent average probability of occupancy to teach its curriculum. Expanding channel capacity to allow individual selection of instructional programs on demand would require a much greater number of channels. By analogy, this would require a channel capacity more nearly comparable to the number of books in the Rensselaer library (for Monomedia) than the number of classrooms on the Rensselaer campus (for Micromedia).

Given these numbers, it is not surprising that considerable effort has gone into reducing the bandwidth required for a display. The large 6 MHz bandwidth associated with video channels is primarily associated with the requirement for moving picture displays in conventional television. The picture is changed 30 times a second to provide the illusion of motion. Most educational applications do not require a moving picture display and would prefer to trade motion for resolution. The relevant technology has already been discussed in Chapter [illegible] of this report.

4.2.3.4 Effect of Cable Television on the Cost of Education

Our present system of education is experiencing financial crises at all levels. It may be that, discounting the effects of inflation, we will never again be able to afford our present level of education as measured in cost per pupil. Since most of a school budget is spent on teacher salaries, the cost of education cannot be significantly reduced unless teacher productivity or, equivalently, student/teacher ratios can be raised .

The advantages of televised instruction are largely associated with improved programming rather than the quality of the medium. That is, a more elaborate, more carefully rehearsed and edited presentation can be viewed. Such presentations are significantly more expensive than conventional instruction. Sesame Street cost 600 K$ for research and 24 K$ per hour of program in its first year.[4-11] Network television programs cost more than 50 K$ for each half hour.[4-12] By contrast, the cost of instruction by a university professor paid 20 K$ a year and lecturing 10 contact hours/week for 30 weeks a year is about $100 per hour, assuming 50 percent overhead. (Instruction in elementary and secondary schools is less expensive by about a factor of 10.) Assuming an average class size of 30 means that, under the most favorable conditions, televised instruction of this quality would only become cost effective for viewing audiences of over 10 000. Thus, most of the advantages associated with cable television in education require it to be a mass medium.

It may be argued that a figure of 24 K$ per hour is excessive for the cost of programming. The production facilities at Oregon State University, which provides 1300 hours of cable television programming a year,[4-13] cost about 170 K$ for equipment and 70 K$/year for maintenance staff.[4-14] The office of Instructional Media at Rensselaer estimates that a 10 minute film cost 3 K$ to produce depending on the complexity (need for graphics, etc.) of the topic. Video tape recording costs $100 for a 10 minute tape. It is somewhat less expensive because the editing process is less complex.

Note that the instructional services we are discussing could equally well use film. A broad-band cable system only provides an alternative means of delivering a filmed or video taped presentation. It is doubtful that such a system can cost less than direct access to an audio-visual library. Although the cost of maintaining the collection could probably be lowered if films were only handled by skilled personnel in a central location, it is not clear that this would offset the additional costs associated with cable distribution.

The most extensive experiment along these lines was conducted by Bell-Telephone Research Ltd. who developed and operated an on-demand educational program retrieval system in Ottawa, Ont., Canada.[4-15] Four schools covering grades Kindergarten to Grade 13 were connected to a program information bank and program distribution center containing 2600 video tapes and films on a variety of topics selected by a committee of teachers.

Usage was reasonably heavy. In May 1970, 1640 programs were transmitted on demand into the 130 classrooms involved. The project was discontinued because the school system could not see any clear advantage over their previous practice of sending a truck carrying films between schools. Costs apparently were comparable.

Whether televised or, more generally, broad-band cable delivered instruction can lower, or at least not raise, the cost of education depends critically on whether it supplements or supplants our present system of classroom education.

By and large, certified instruction is under the control of accredited institutions which have a long-standing commitment to classroom instruction. This means that Instructional Television, television which "is closely related to the work of organized formal educational institutions,"[4-16] has generally been used only to supplement existing programs of classroom instruction. In such a situation, improved accessibility means that "students who must be absent because of illness or handicap can join their classmates at school via cable."[4-17] Even so, Ms. Carpenter quickly points out that this would require one channel for each class and would quickly overwhelm the capacity of a broad-band cable system. Such a use of cable television would be very expensive and would greatly increase the cost of education. Ms. Carpenter goes on to comment that "today's byword is 'You can't expect to save money in education by using technology'."[4-18]

There are few cases in which any form of instructional television has been demonstrated to lower the cost of education. Anaheim, Calif. was able to save two classrooms and two teachers for every 150 5th and 6th graders by redeploying them in 75-student rooms for televised instruction under the direction of two teachers. As a result, TV instruction was able to handle twelve percent of the curriculum for less than five percent of the total district budget.[4-19] L. Johnson[4-20] has estimated a cost savings of 32 K$ at Oregon State University resulting from the use of televised instruction to reduce 112 contact hours for 50-student classes to 20 contact hours. This estimate depends crucially on class size and the amount of time spent by faculty members in noninstructional activities. Replacing 25-student classes would produce savings of 128 K$; replacing 100-student classes would produce negative savings (i.e., additional costs) of -16 K$.

More savings may be possible if broad-band cable delivery replaces classroom instruction. The certification of such instruction is a key question. The Chicago TV college has provided courses for credit to about 100 000 students from 1956 to 1970.[4-18] To have a major impact, costs need to be significantly lower than the 5 to 10 K$ per year cost of university education. To the extent that higher education is subsidized by state taxes or private endowments, the cost to parents or university students is significantly less. Similar subsidies would be needed to make televised instruction competitive. As previously mentioned, primary and secondary education costs are lower by about a factor of 10 per pupil.

The dependence of cost on market size is a strong function of the way educational programming is implemented. Programming costs per viewer are lowered if a large audience shares them. Distribution costs are minimized if the maximum number of people watch the same program at the same time. Greater individualization raises distribution costs by raising the requirement for channels in proportion to the number of groups watching the same program at different times. The per subscriber cost of achieving a given performance level increases in direct proportion to the cost of modifying the subscriber terminal, but this cost can be reduced as increased headend facilities are traded for terminal modifications.

One needs to remember that a given performance level can support a wide variety of different services. This may mean that developing a performance level for entertainment services can, in effect, subsidize expanded educational services. Alternatively, it may be that the market for a given performance level of any particular service is too small to support its development even though the usage of such a performance level by all services might be large. In such a case, development of a given performance level is unlikely without external subsidy.

4.2.3.5 Individual Preference

We speculate that, for comparable costs and certification, individual preference for televised instruction in the home would be relatively high. We base this conclusion on three considerations. In the first place, there has been a major shift from movie going to television viewing. Between 1959 and 1969 television ownership rose from 0.1 to 1 sets per household while movie attendance dropped from 2 to 0.76 movies per week per household.[4-21] This indicates a strong tendency to favor the convenience, safety, and thrift of home viewing over the higher quality presentation of a movie in a theater. Secondly, the experience of the Chicago TV College indicates a high degree of viewer interest in televised instruction. They estimate that there are about 250 000 regular and 500 000 frequent, but not daily, viewers of each semester's courses.[4-22] Finally, the market for TV games such as Odyssey by Magnavox suggests that viewers are willing to participate interactively in televised instruction. These data indicate that individual preference would tend to favor the growth of educational service delivery by telecommunications.

4.2.3.6 Institutional Resistance

A growing acceptance of televised instruction in the home would have revolutionary effects on our present educational system with its commitment to classroom education. The situation is aggravated by salary inflation, stagnant productivity, and a declining school age population. The growing acceptance of the open university concept (a correspondence school for higher education), as illustrated by the New York State Regents sponsorship of Empire State University, is a further trend that should be noted. It is a competing trend since it requires televised instruction to offer some advantage in terms of accessibility, quantity, quality, or cost over a correspondence school based on the postal system.

The prospect of significant change and the natural inertia of our present educational system provides a basis for strong instutional resistance to widespread use of cable delivered instructional television. Ms. Carpenter[4-23] summarizes this problem as follows: "Lack of appropriate, high-quality programming and inadequate provisions for its utilization are not the primary barriers to the use of television in education. Rather they are symptoms of a pervasive problem - lack of interest or outright resistance to major change by the education community ... educators whether faculty or administration, find it difficult to change their concept of what the process of education should be." Overcoming this inertia requires a sustained, concentrated effort before any benefits of instructional television are realized. In the Anaheim school district instructional committees cochaired by television teachers and classroom teachers have been formed at each grade level and subject area.[4-24] During its first year of operation, the Children's Television Workshop spent 700 K$ in 12 metropolitan areas and 400 K$ on promotional media to promote widespread reception of Sesame Stree.[4-11] Indeed, resistance to the utilization of instructional television is well documented.[4-25]

L. Johnson[4-26] discusses the jurisdictional and institutional barriers Oregon State University had to overcome to offer credit for its televised courses to viewers who were not regularly enrolled OSU students. He notes that "One of the most serious problems in instructional television is institutional reluctance to share programming. Although it may well be in society's interest that expanded use be made, impediments involving organizations and personalities, copyright problems, and miscellaneous red tape frequently obtrude."

Johnson further reports the much more limited use of cable television by the University of Oregon in an environment comparable to that of Oregon State University. He suspects that this is due to the fact that OSU concentrates on science and engineering while UO concentrates on the liberal arts. An additional complication may be UO's disappointing experience with the Inter-Institutional Project on Televised Instruction. This seven year project initiated in 1957 apparently foundered because the institutions were unwilling to use a rival institution's programs to lower instructional costs.[4-27]

It is interesting to note that the successful launching of televised instruction in both the Anaheim School District and Oregon State University apparently occurred at a point of crisis when existing facilities could not accommodate an overwhelming enrollment.

4.2.4 Commercial and Business Services

The existence of channels dedicated to particular communities or districts within a metropolitan area could provide an advertising medium for neighborhood shops and businesses. At the same time, channels dedicated to particular groups could provide an advertising medium for specialized stores and services catering to their interests. How the costs of these channels should be shared by subscriber and advertisers is an issue which needs further study.

It would be highly desirable, from the point of view of the advertiser as well as the consumer, to develop a service which provides the consumer with information about various sources for the goods and services in which he or she is particularly interested. Consumer selection of the categories of goods or services on which information is desired could be accomplished with a Touch-tone telephone.

A further innovation is remote purchasing as well as viewing in which the telecommunication system could automatically transfer payments and record accounts for the purchaser, the store, and the purchaser's bank. This is a natural extension of present trends in businesses and banks, and should be discussed more fully under financial services. Once again, such a development would lead to changes in the work habits and requirements for sales personnel. This would need to be considered very carefully before such a scheme could be implemented successfully. In addition, comparable attention needs to be paid to developing acceptable business practices and procedures for processing and recording the transactions. This is a clear example of a situation in which hardware must be developed in close interaction with the development of procedures. Successful innovations in the use of telecommunications to process financial transactions will require careful attention to all aspects (technical, economic, and social) of the system to be developed.

Many of the commercial services mentioned here would apply to businesses as well. In fact, business organizations are more likely to invest in such services than most consumers if they can be shown an economic benefit. Beyond this, the increasing substitution of communication for transportation in the conduct of business could have a marked effect on the structures and location of organizations. There are differences in the ease of implementation of particular services, however. For example, one should determine the relative needs for point-to-point two-way video, facsimile, or data communication before deciding how broadband business networks should be structured.

Several experiments have been conducted on the effects of teleconferencing in which conferences are conducted by means of a telecommunications network. In general, these experiments indicate that video teleconferencing is at leat equivalent to face-to-face conferences and may lead to more effective conferences.[4-28] Paul Polishuk of the U.S. Office of Telecommunications has summarized current research on the substitution of telecommunications for travel.[4-29] He concludes that "there has been little substantive social science research on the impact of telecommunications technology" and that "considerably more quantitative research is required to assess the technical, behavioral, social, and economic impact of both narrow-band and wide-band telecommunications technologies for these applications."

4.2.5 Health Services

Although micromedia could play a significant role in medical education, the principal value of a telecommunication system would seem to lie in its ability to allow the physician to view or monitor his patient. A video pickup system was tested at the Boston airport where it seems to be quite helpful in providing emergency care. Such a system allows a nurse or attendent on duty at the site to have a reservoir of doctors and medical specialists on call at all times.

There are a number of cases in which a remote video pickup system could supplement our present health care system. For one thing, it would provide the electronic equivalent of hourse calls. Similarly, it could provide the equivalent of a doctor in residence in schools and businesses which are presently too small to afford one. Portable video cameras carried in ambulances, fire trucks, or police cars could likewise be used to provide medical support in accidents or emergiencies.

The video system should be designed for a variety of applications. Thus, it should be possible for the doctor in attendance to relay the call to other doctors who are specialists in the particular area concerned. Likewise, such a system could be used as an early-warning system for hospitals, allowing them to prepare specialized facilities in advance of the ambulance's arrival. Finally, a number of remote sensing devices could be fed into the communication systems to allow paramedical personnel to monitor and perhaps treat the patient under the supervision of a doctor remotely coupled to the scene.

There is a growing literature on telemedicine - the use of interactive video telecommunication in providing remote medical care. The anticipated benefits included:

1. Increased geographic centralization of specialized functions coupled with decentralized medical practice by neighborhood clinics and general practiticioners.
2. Redistribution of health care from areas of abundance (high-income urban and suburban) to areas of scarcity (low-income urban and rural).
3. Mitigation of depersonalized service resulting from organizational changes already underway to decrease the inefficiency of health-care systems.

The above list of anticipated benefits is taken from a recent article by Maxine Rockoff of the U.S. Public Health Service, summarizing seven exploratory experiments in health-care delivery by broad-band telecommunications.[4-30] Park has also published a review of current efforts in the use of two-way television for health care delivery.[4-31]

Conrath, et.al.[4-32] report the results of a preliminary study of the efficiency and effectiveness of two-way communications systems - color television, black-and-white television, and hands-free telephone - compared with physically present consultation. They conclude that there were no significant differences between the four modes in the time taken to complete the diagnostic consultation, accuracy of diagnosis, and effectiveness of patient management. Patients and doctors preferred the telecommunication modes in the above order.

Rockoff reports that patient acceptance of telemedicine was never a problem.[4-30] She comments that "what started out as a program to assess the potential utility of visual telecommunication in health-care systems has taught us more than anything else that (its) utility will have to be determined -- by communications engineers in partnership with biomedical engineers, health-care consumers, health-care providers, economists, sociologists, psychologists, lawyers, and legislators."[4-30] In a later aritcle,[4-33] she lists a number of potentially harmful impacts and provides a rebuttal based on her experience with health-related telecommunication projects.

The single largest factor in limiting the expansion of these services is likely to be their acceptance by the medical profession. Issues such as governmental regulation, medical liability and impact on physicians' earnings are likely to be of crucial importance in the successful expansion of these services.

Two groups of persons for whom the use of a remote monitoring and viewing system might significantly reduce the cost of health care are the elderly and the invalid.[4-2] Through the use of a telecommunications network it might be possible to provide health care in ordinary apartment complexes which would approximate that of a nursing home. The care and housing of the elderly is becoming a significant social and economic problem throughout the nation, and development of a telecommunications system which would provide for home care on demand would seem to be of significant social benefit.

4.2.6 Welfare and the Ghetto

When considering the problem of welfare in general and the ghetto in particular, one needs to recognize that the ghetto resident faces all of the problems that the rest of society faces. However, problems such as unemployment, undereducation, disease, and lawlessness are more intense in the ghetto, and the ghetto resident has fewer resources with which to cope with them. Thus, if an expanded telecommunications system can provide services for society as a whole, the need for these services is much greater in the ghetto.

At the present time, television programs play a very important role in the cultural life of the ghetto, and are a significant factor in determining the aspirations of ghetto youth. Educational programs such as Sesame Street have already had a significant influence on pre-school education, one of the ghetto's greatest needs. Several other types of educational programs are also possible. Thus, programs dealing with vocational and homemaking skills, and preparatory training for eighth grade and high school equivalency tests, would all be of benefit to an undereducated adult population whose lack of basic skills keeps them unemployed or underemployed. Increasing the educational level of citizens in the ghetto is necessary if families are ever to be able to break out of the cycle of unemployment, poverty, and welfare.

Other specialized programs might include an employment information service. By coupling a video display with an audio response system it would be possible for individuals to be contacted or apply for jobs as they become available. In the same way, a video-audio or two-way video system could be used to supplement or replace home visitation for welfare counseling, medical care, or family assistance.

4.2.7 Public Safety

Considerable attention has been given recently to the use of electronic devices to increase public safety. This area involves a complex bundle of interrelated problems, of both a social and a regulatory nature. In this section we will consider the potential impact of telecommunications on public safety by examining the role it could play in communication, emergency warning, and identification. The following remarks apply equally well to fire protection, civil defense, and law enforcement.

Effective communication systems are essential for providing the rapid coordination of activities required to maintain public safety in emergencies. Broadcast systems are necessary, since communication with and between moving vehicles is required. Cable technology will thus play no direct role in this area, although combination broadcast - cable links could be used in special circumstances.

Emergency warning and monitoring systems are a fertile field for further investigation, particularly in the area of law enforcement where it takes the form of surveillance. This is a major function performed by policemen walking their beat, and is as important for deterrence of crime as it is for the apprehension of criminals. Remotely controlled television cameras have been used for surveillance, although a study by the National Academy of Engineering[4-2] indicates that their cost would be prohibitive in most public situations (e.g., street corners). Such cameras are often used for maintaining a 24 hour watch in the lobbies of apartment complexes and other private buildings. More promising perhaps, is the use of other electronic devices, such as intrusion alarms, as remote sensing devices coupled into the audio channel of a telecommunications network. The television camera on a two-way video system could be used to send a visual record of events occuring within its field of view when triggered by an intrusion alarm.

A major problem in law enforcement at present is the lack of sufficient evidence to secure a conviction once an arrest has been made. The use of portable video cameras and video cameras and video tape recorders to make on-the-spot recordings of events would provide a valuable record for later investigations and court proceedings. Also, as in the case of remote medical monitoring, a video camera would allow specialists to be consulted more conveniently in all types of emergencies. Further investigations and field trials are needed to see if portable video cameras would be a practical, effective, and economical aid to public safety.

4.2.8 Postal Services

Many of the above-mentioned functions are presently provided in whole or in part through the mail. Entertainment and information are provided by magazines. Many correspondence courses and mail-order catalogs exist. Everyone is familiar with bulk advertising addressed to the resident of a particular address. Most bills come through the mail and are paid by checks which are sent through the mail. To the extent that these functions can be supplied more economically and effectively through telecommunications, the relative demand for postal services should decrease. One question which needs close examination is why it needs to be more expensive to make a cross-country call than it is to send a letter the same distance. This is particularly surprising since one might expect on a technological basis that the costs of *transmitting* information should be much less than the cost of *transporting* the same amount of information.

In broad perspective, the question raised by the impact of telecommunications on postal services is the extent to which a permanent record is needed to perform any of the above functions. While there are legal requirements for documents in many cases, many records can be stored more effectively on film or magnetic tape than they can on paper. It would be instructive to study the extent to which our present civilization is dependent on an adequate supply of paper. The Connecticut Research Commission has found that provision for the transmission of printed documents by facsimile was an essential prerequisite for the relocation of businesses in Connecticut.[4-2] Although this is particularly true for insurance companies, which are the dominant type of business in Connecticut, the production and transmission of documents of one sort or another is a major concern of most companies.

What is the essential difference between a permanent record and a television presentation? At present, there are several differences in function as well as form. The relative information contents of a printed page and a television screen, differ significantly, and this will cause corresponding effects on the psychological responses of persons interacting with these media. Information is needed on the relative ease with which a person can read words on a television screen compared with words on a graphic display panel or words on a printed page. The second difference between a printed page and a television screen is the control that the reader has over the rate at which material is presented. The third difference is the relative freedom the reader has to select the material he wishes to read. The available technology must provide the video screen viewer with image quality, rate control, and freedom of selection comparable to those he now enjoys as a printed page reader before telecommunication systems can be effective in providing postal services. The use of broadband communication networks for high speed, high quality facsimile transmission could be a significant factor in this area

4.2.9 Meter Reading Services

Although the remote monitoring of electric and water meters has often been proposed, the present costs of meter reading are quite low. This makes it difficult to find remote sensors which are economically competitive. Thus, except for large apartment or housing complexes where many units need to be monitored in one location, meter reading systems may make little use of telecommunications in the foreseeable future.

One service for which the automatic monitoring of costs and automatic billing procedures will be needed, however, is the type of multipurpose broadband telecommunications system we have been contemplating throughout this report. Since it will offer a wide range of services it will need to have a corresponding range of price schedules. Since each user would be expected to make his own individual selection of services to fulfill his needs and interests, bill preparation would have to be designed into the telecommunications system from its inception. An exactly parallel situation is the billing service used by the telephone system, which keeps track of the many different services used, and bills accordingly.

4.2.10 Private Communications

Beyond the wide range of public services we have discussed, lies an even vaster and less well defined range of private services. The importance of this area can be seen in the fact that it is the demand for private business and personal conversations that is the basis for the present Bell Telephone

System. Clearly, an expanded broad-bandwidth telecommunications system of the type we have described has significant implications for private as well as public communications. The extent to which video communications will augment the present audio telephone system, depends on the extent to which each home has a television camera as well as a television receiver.

It is probably unnecessary to attempt to outline the private uses to which such a broad-band telecommunications system could be put; every business or household will have its own individuals' needs and desires. Nonetheless, the very possibility of private use of the telecommunications network has profound technical, economic, and social implications for the design of the entire system.

In the first place the communication links and exchanges associated with such a system should be designed to be compatible with two-way video inputs; in particular it would be compatible with Bell's Picturephone system. This will probably require a certain amount of bandwidth expansion and compression capability within each local exchange.

The extent to which each householder is required to pay the cost of the overall system by means of rent or taxes and the extent to which costs are optional on the basis of the service actually used will have an important bearing on the utilization of the network for this purpose.

An important difference exists between the telephone system and the two-way video link as envisioned in a conventional cable system. With the telephone, a separate point-to-point link is set up for each conversation. With the conventional cable system, upstream channels are shared by all users. Thus, safeguards must be built into the system so that individual privacy will not be violated and the householder will be protected against undesirable inputs. These may take the form of scrambled or coded signals, which can only be reviewed by the authorized party. Alternately, we can envision the use of an SDM broadband distribution system as described in Chapter 2 to provide point-to-point links between subscribers.

REFERENCES

4-1 K. Rose and R.J. Gutmann, "Impact of Cable Television on Education," IEEE Transactions on Communications, COM-23, 1164 (1975)

4-2 "Communications Technology for Urban Improvement," Committee on Telecommunications, National Academy of Engineering, Report to the Department of Housing and Urban Development under Contract No. H-1221. (June 1971).

4-3 E. M. Dickson and R. Bowers, "The Video Telephone, a New Era in Telecommunications," Report NSF-RA-S-703-004, Cornell University (June 1973).

4-4 E. Leonard, A. Etzioni, et. al., "Minerva: A Participatory Technology System," Bulletin of Atomic Scientists, p. 4 (November 1971).

4-5 P. Doty and R. Zussman, "Electronic 'Town Meetings': Two Experiments in Participatory Technology," IEEE Transactions on Communications, COM-23, 1126 (1975).

4-6 A. G. Oettinger, Run, Computer, Run - The Mythology of Educational Innovation, New York: Collier, 1969.

4-7 P. Carpenter, "Cable Television: Uses in education," RAND Corp., Santa Monica, Calif., Rep. R-1143-NSF, May 1973.

4-8 A. Etzioni, "Human Beings are Not Very Easy to Change After All," The Saturday Review, vol. 55, June 3, 1972.

4-9 W. Schram, "What we Know About Learning From Instructional Television," in Educational Television in the Next Ten Years. Stanford, Calif.: Institute for Communication Research, 1962, ch. 2.

4-10 S. Wade, "Hagerstown: A Pioneer in Closed-Circuit Televised Instruction," in New Educational Media in Action: Case Studies for Planners, vol. 1. Amsterdam, The Netherlands: UNESCO, International Institute for Educational Planning, 1967.

4-11 D.D. Connell, "How Sesame Street raised and spent eight million dollars," Dividend, Graduate School of Business Administration, Univ. Michigan, Ann Arbor, Winter 1971.

4-12 "On the cable - The television of abundance," in Report of the Sloan Commission on Cable Communications. New York: McGraw-Hill, 1971, p. 235.

4-13 "1[illegible]00 hours of programming a year - At no cost to the cable company," Broadcast Management Engineering, vol. 10, p. CM/E4, Nov. 1974.

4-14 L.L. Johnson, "Cable television and higher education: Two contrasting experiences," RAND Corp., Santa Monica, Calif., Rep. R-828-MF, Sept. 1971.

4-15 C. A. Billowes, "On-demand educational television program retrieval system for schools," Proc. IEEE (Special Issue on Engineering Education), vol. 59, pp. 998-1000, June 1971.

4-16 "Instructional television fixed service," Educational Products Information Exchange Institute, New York, N. Y., Educational Product Rep. 31, 1971.

4-17 P. Carpenter, "Cable television: Uses in education," RAND Corp., Santa Monica, Calif., Rep. R-1143-NSF, p. 5, May 1973.

4-18 ———, "Cable television: Uses in education," RAND Corp., Santa Monica, Calif., Rep. R-1143-NSF, p. 15, May 1973.

4-19 R. Bretz, "Closed-circuit ITV logistics - Comparing Hagerstown, Anaheim and Santa Ana," J. NAEB, July-Aug. 1965.

4-20 L.L. Johnson, "Cable television and higher education: Two contrasting experiences," RAND Corp., Santa Monica, Calif., Rep. R-828-MF, p. 13, Sept. 1971.

4-21 M.L. DeFleur, Theories of Mass Communication, 2nd ed. New York: McKay, 1970.

4-22 R. Bretz, "Three models for home-based instructional systems using television," RAND Corp. Santa Monica, Calif., Rep. R-1089-USOE/MF, Oct. 1972.

4-23 P. Carpenter, "Cable television: Uses in education," RAND Corp., Santa Monica, Calif., Rep. R-1143-NSF, p. 30, May 1973.

4-24 "Teaching with television," Dep. Instructional Media, Anaheim School District, Anaheim, Calif.

4-25 R.V. Wagner et al., "Study of systemic resistances to utilization of ITV in public school systems," American Univ., Washington, D.C., Rep. ED 030 012, Feb. 1969.

4-26 L.L. Johnson, "Cable television and higher education: Two contrasting experiences," RAND Corp., Santa Monica, Calif., Rep. R-828-MF, p. 16, Sept. 1971.

4-27 G. Starlin and J.E. Lallas, "Inter-institutional teaching by television," Eugene, Ore., Final Rep. 1957-1964, Aug. 1964.

4-28 K. Kohl, T.G. Newman, and J.F. Tomey, "Facilitating Organizational Decentralization through Teleconferencing", IEEE Transactions on Communications, COM-23, 1098 (1975).

4-29 P. Polishuk, "Review of the Impact of Telecommunications Substitutes for Travel", IEEE Transactions on Communications, COM-23, 1089 (1975).

4-30 M.L. Rockoff, "An Overview of Some Technological/Health-Care System Implications of Seven Exploratory Broad-Band Communication Experiments," IEEE Transactions on Communications, COM-23, 20 (1975).

4-31 B. Park, "An Introduction to Telemedicine: Interactive Television for Delivery of Health Services," The Alternate Media Center, New York University, New York, 1974

4-32 D.W. Conrath, et al., "A Preliminary Evaluation of Alternative Telecommunication Systems for the Delivery of Primary Health Care to Remote Areas," IEEE Transactions on Communications, COM-23, 1119 (1975).

4-33 M.L. Rockoff, "The Social Implications of Health Care Communication Systems", IEEE Transactions on Communications, COM-23, 1085 (1975).

5. POTENTIAL REQUIREMENTS FOR BROADBAND TELECOMMUNICATION SERVICES

5.1 Overview

In Section 2 we indicated the constraints on channel capacity of various distribution systems and the technological alternatives for alleviating these constraints. The capacity required of future broadband communication networks depends critically on the future demand for individualized, interactive services. Unfortunately, as shown in Section 3.2, it is difficult to establish reliable estimates of demand even for conventional cable television systems. To estimate the capacity required of future broadband cable networks, we must first estimate the kinds and amounts of telecommunication services required by BCN subscribers.

In the next section we review Baran's estimate of the "potential market demand" for 30 two-way information services to the home. We then use these estimates in the following section to derive approximate quantitative estimates of service requirements for BCN's. Before proceeding, it may be helpful to clarify Baran's use of the word demand. His estimates of the price, number, and duration of various transactions do not define a demand curve which displays price (P) as a function of quantity (Q). However, they do define an area in the PQ-plane in which his respondents feel the equilibrium demand would lie. Consequently, we feel that the range of his estimates is a more reliable guide to future demand than their median value.

In the following sections we show how Baran's data can be used to derive estimates of usage and bandwidth requirements for interactive services. We summarize the results of an analysis of the impact of two-way interactive communications on cable TV systems which was conducted under this program[5-20].

5.2 Baran's Demand Forecast

Baran's estimate of potential demand for two-way information services to the home is certainly the most widely known guide to the future market for such services[5-1, 5-2, 5-3, 5-4]. His estimate was arrived at by the Delphi technique using a panel of experts*. The experts were individuals who generally were proficient in the technological aspects of the future systems and were often broadguaged ' company philosopher' types.

For each of the 30 potential services panelists were asked to give estimates for the following eight service characteristics:

1. Average dollar value of one conversation (low, median, and high high estimates).
2. Duration of one entire transaction from completion of dialing to disconnect.
3. Percentage of actual transmission of data or message during transactions.
4. Average number of transactions per month, per home.
5. Percentage of service home subscribers could be expected to pay.
6. Most likely year of mass introduction in the United States (earliest, median, and latest estimates).
7. Percentage penetration of households five years later.

("The most likely entrepreneur to offer this service" was also asked but was not reported in Reference 5-1)

Table 3.1 is taken directly from Baran's work and presents brief descriptions of the thirty potential services as given to the respondents[5-1]. A more expanded discussion of these services is also given in References 5-1 and 5-2.

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*The Delphi technique uses questionnaires to collect the estimates of expert respondents who remain anonymous[5-5,5-6,5-7]. It is an iterative technique since respondents were given the results of the first-round questionnaire and asked to reestimate all numerical forecasts in light of the other panelists' responses. Since the dispersion of estimates is narrower after the second round, the second round estimate is more precise. This precision may be spurious, however. A Delphi study estimating quantities whose magnitude was known showed that the responses often converged to the wrong value[5-8].

Reference 5-1 notes that the reliability of the study is somewhat reduced for two reasons. For one thing, the definitions of services were brief and in some cases ambiguous. Hence, different respondents may have interpreted a given question differently. Second, there is an overlap between some of the individual services. Increased use of one service may increase or diminish use of another. For example, Electronic Shopping at Home overlaps Cashless-Society Transactions. Because of such overlaps, the aggregate estimates for each category of services probably contain some double counting. Counterbalancing this is the realization that the list of 30 is incomplete; major services such as health services and home security systems were omitted. Finally, the small number of respondents (12 to 16) introduces additional statistical uncertainties. Even so, Baran's study is the only data available for estimating potential demand for cable services.

Table 5.2 lists subscriber services and usage forecasts taken from Reference 5-1. We have grouped the services in the categories Baran has used, and have attempted to list the categories in order of consumer acceptance. For example, the first category listed is Entertainment because we feel this would require the least change in subscriber behavior. The subscriber is used to viewing movies on television. Requesting a movie from a library is a natural extension of his present activity; subscribing to a dedicated information service is not. Within a given category, the services have been listed in order of decreasing market size according to Baran's estimates.

The fact that a new service may closely resemble a present service does not mean that it will be correspondingly easy to implement. In fact, implementing the video movie library would require a much larger bandwidth than implementing a personalized calendar. Bandwidth requirements would be

Table 5.1

BRIEF DESCRIPTIONS OF POTENTIAL HOME INFORMATION SERVICES

1. CASHLESS-SOCIETY TRANSACTIONS. Recording of any financial transactions with a hard copy output to buyer and seller, a permanent record and updating of balance in computer memory.

2. DEDICATED NEWSPAPER. A set of pages with printed and graphic information, possibly including photographs, the organization of which has been predetermined by the user to suit his preferences.

3. COMPUTER-AIDED SCHOOL INSTRUCTION. At the very minimum, the computer determines the day's assignment for each pupil and, at the end of the day, receives the day's progress report. At its most complex, such a service would use a real-time, interactive video color display with voice input and output and an appropriate program suited to each pupil's progress and temperament.

4. SHOPPING TRANSACTIONS (STORE CATALOGS). Interactive programs, perhaps video-assisted, which describe or show goods at request of the buyer, advise him of the price, location, delivery time, etc.

5. PERSON-TO-PERSON (PAID WORK AT HOME). Switched video and facsimile service substituting for normal day's contacts of a middle-class managerial personnel where daily contacts are of mostly routine nature. May also apply to contacts with the public of the receptionist, doctor, or his assistant.

6. PLAYS AND MOVIES FROM A VIDEO LIBRARY. Selection of all plays and movies. Color and good sound are required.

7. COMPUTER TUTOR. From a library of self-help programs available, a computer, in an interactive mode, will coach the pupil (typically adult) in the chosen subject.

8. MESSAGE RECORDING. Probably of currently available type but may include video memory (a patient showing doctor the rash he has developed).

9. SECRETARIAL ASSISTANCE. Written or dictated letters can be typed by a remotely situated secretary.

10. HOUSEHOLD MAIL AND MESSAGES. Letters and notes transmitted directly to or from the house by means of home facsimile machines.

11. MASS MAIL AND DIRECT ADVERTISING MAIL. Higher output, larger-sized pages, color output may be necessary to attract the attention of the recipient--otherwise similar to item 10 above.

12. ANSWERING SERVICES. Stored incoming messages or notes whom to call--possibly computer logic recognizing emergency situation and diverting the call.

13. GROCERY PRICE, LIST, INFORMATION, AND ORDERING. Grocery price list is used as an example of up-to-the-minute, updated information about perishable foodstuffs. Video color display may be needed to examine selected merchandise. Ordering follows.

14. ACCESS TO COMPANY FILES. Information in files is coded for security; regularly updated files are available with cross-references indicating the code where more detailed information is stored. Syntheses also may be available.

15. FARES AND TICKET RESERVATION. As provided by travel agencies now but more comprehensive and faster. Cheapest rates, information regarding the differences between carriers with respect to service, menus, etc. may be available.

16. PAST AND FORTHCOMING EVENTS. Events, dates of events, and their brief description; short previews of future theater plays; and recordings of past events.

17. CORRESPONDENCE SCHOOL. Ta[illegible]r live high school, university, and vocational courses available on request with an option to either audit or graduate. Course on TV, paper support on facsimile.

18. DAILY CALENDAR AND REMINDER ABOUT APPOINTMENTS. Prerecorded special appointments and regularly occurring appointments stored as a programmed reminder.

19. COMPUTER-ASSISTED MEETINGS. The computer participates as a partner in a meeting, answering questions of fact, deriving correlations, and extrapolating trends.

20. NEWSPAPER, ELECTRONIC, GENERAL. Daily newspaper, possibly printed during the night, available in time for breakfast. Special editions following major news breaks.

21. ADULT EVENING COURSES ON TV. Noninteractive, broadcast mode, live courses on TV--wider choice of subjects than at present.

22. BANKING SERVICES. Money orders, transfers, advice.

23. LEGAL INFORMATION. Directory of lawyers, computerized legal counseling giving precedents, rulings in similar cases, describing jurisdiction of various courts and changes of successful suits in a particular area of litigation.

24. SPECIAL SALES INFORMATION. Any sales within the distance specified by the user and for items specified by him will be "flashed" onto the home display unit.

25. CONSUMERS' ADVISORY SERVICE. Equivalent of Consumer Reports, giving best buy, products rated "acceptable", etc.

26. WEATHER BUREAU. Country-wide, regional forecasts or special forecasts (farmers, fishermen), hurricane and tornade warnings similar to current special forecast services.

27. BUS, TRAIN, AND AIR SCHEDULING. Centrally available information with one number to call.

28. RESTAURANTS. Following a query for a type of restaurant (Japanese, for instance), reservations, menu, prices are shown. Displays of dishes, location of tables, may be included.

29. LIBRARY ACCESS. After an interactive "browsing" with a "librarian computer" and a quotation for the cost of hard copy facsimile or a slow-scan video transmission, a book or a magazine is transmitted to the home.

30. INDEX, ALL SERVICES SERVED BY THE HOME TERMINAL. Includes prices or charges of the above, or available communications services.

Table 5.2: Demand Forecasts for Interactive Services

	Single Transaction Duration (Min.)	Data Transmission as a Percentage of Connect Time	Avg. No. Trans. per mon./home	Yr. Intro. in U.S.	% Penetration of Households: 5 Years After Introduction	Price of Service After 5 Years $/Transaction
1. Entertainment						
1.1 Plays, Movies from Video Lib.	100, 80, 75	100, 100, 97	10, 10, 5	1983, 1980, 1975	15, 10, 5	4, 1.5, 0.5
1.2 Calendar of Past, Forthcoming Events	5, 3, 3	85, 80, 75	10, 7, 5	1985, 1980, 1980	10, 5, 3	0.225, 0.075, 0.04
1.3 Restaurant Info.	5, 3, 3	90, 80, 80	7, 5, 5	1985, 1980, 1980	10, 5, 5	0.1, 0.05, 0.0375
2. Information						
2.1 Gen. Newspaper	12, 10, 5	95, 95, 90	30, 30, 30	1990, 1985, 1980	10, 5, 5	1.5, 0.75, 0.15
2.2 Dedicated Newspaper	30, 10, 5	100, 90, 85	30, 30, 25	1990, 1983, 1980	20, 10, 5	1.0, 0.45, 0.3
2.3 Legal Info.	10, 10, 10	80, 75, 65	5, 5, 1	1990, 1985, 1985	5, 3, 2	1.0, 0.25, 0.15
2.4 Lib. Access	10, 10, 7.5	90, 90, 80	10, 5, 3	1985, 1985, 1980	10, 5, 3	0.315, 0.2, 0.075
2.5 Daily Calendar, Appt. Reminder	2, 1, 1	90, 80, 80	27, 25, 20	1985, 1983, 1980	10, 5, 3	0.31, 0.2, 0.12
2.6 Weather Bureau	2, 1, 1	90, 90, 90	30, 15, 10	1980, 1978, 1975	15, 5, 3	0.3, 0.1, 0.075
2.7 Services Index	5, 3, 3	90, 80, 80	20, 10, 5	1985, 1980, 1978	10, 5, 5	0.5, 0.1, 0.05
2.8 Trans. Scheduling	3, 1.25, 1	90, 80, 80	10, 5, 2	1980, 1977, 1977	10, 5, 5	0.1, 0.035, 0.02
2.9 Fares, Ticket, Reservations	5, 5, 3	60, 50, 50	5, 5, 2	1980, 1980, 1978	5, 5, 2	0.125, 0.05, 0.015

TABLE 5.2 (Cont.)

	Single Transaction Duration (Min.)	Data Transmission as a Percentage of Connect Time	Avg. No. Trans. per mon./home	Yr. Intro. in U.S.	% Penetration of Households: 5 Years After Introduction	Price of Service After 5 Years $/Transaction
3. Education						
3.1 Computer Aided Instr. (CAI)	50, 30, 30	20, 20, 15	30, 20, 20	1985, 1980, 1977	10, 10, 5	5.0, 3.75, 1.44
3.2 Computer Tutor	40, 30, 10	40, 20, 10	12, 10, 10	1990, 1990, 1985	10, 5, 3	1.8, 1.0, 0.72
3.3 Adult Eve. Courses on TV	50, 50, 30	97, 95, 90	10, 8, 5	1980, 1980, 1977	10, 10, 5	1.0, 0.875, 0.35
3.4 Correspondence School	50, 40, 30	90, 85, 70	15, 10, 10	1990, 1990, 1985	10, 5, 2	3.0, 0.75, 0.3
4. Commercial						
4.1 Cashless-Soc. Transactions	1.0, 0.75, 0.5	50, 20, 20	50, 40, 30	1985, 1980, 1980	20, 20, 10	1.20, 1.00, 0.60
4.2 Consumers' Advisory Service	5, 5, 4	80, 70, 70	10, 10, 5	1985, 1980, 1980	10, 5, 5	0.5, 0.4, 0.05
4.3 Shopping Trans. (Store Catalogs)	10, 5, 5	50, 40, 20	20, 10, 10	1985, 1983, 1980	20, 10, 5	1.125, 0.0375, 0.125
4.4 Grocery Shopping	7.5, 5, 5	90, 80, 50	20, 15, 10	1983, 1980, 1980	20, 10, 5	1.4, 0.26, 0.15
4.5 Special Sales Information	5, 3, 2	80, 70, 70	15, 10, 10	1985, 1980, 1980	7, 5, 5	0.5, 0.25, 0.15
5. Business						
5.1 Bus. from Home	30, 10, 10	65, 50, 40	100, 60, 30	1987, 1985, 1985	7, 5, 2	7.5, 3, 1.5
5.2 Computer-Asst. Meetings	35, 30, 7	50, 40, 15	7, 5, 3	1985, 1980, 1980	10, 5, 1	1.75, 0.5, 0.075
5.3 Banking Services	3, 1, 1	80, 60, 50	30, 20, 10	1985, 1980, 1978	10, 10, 10	0.5, 0.35, 0.2
5.4 Access to Co. Files	5, 5, 5	80, 65, 50	30, 10, 10	1985, 1985, 1980	5, 2, 2	1, 0.3, 0.1

TABLE 5.2 (Cont.)

	Single Transaction Duration (Min.)	Data Transmission as a Percentage of Connect Time	Avg. No. Trans. per mon./Home	Yr. Intro. In U.S.	% Penetration of Households: 5 Years After Introduction	Price of Service After 5 Years $ Transaction
6. Person-to-Person Communications						
6.1 Household Mail, Messages	3, 2, 2	[illegible], 90, 90	40, 35, 20	1987, 1985, 1980	20, 10, 5	1.2, 0.6, 0.25
6.2 Mass Mail, Direct Adver.	3, 3, 1	90, 90, 90	32, 20, 20	1990, 1990, 1985	10, 10, 5	1.0, 0.3, 0.2
6.3 Answering Services	3, 2, 1	85, 80, 75	30, 20, 10	1980, 1980, 1975	15, 10, 5	0.56, 0.3, 0.225
6.4 Secretarial Assistance	10, 10, 5	80, 60, 50	15, 10, 5	1980, 1980, 1977	20, 5, 3	2.0, 0.25, 0.125
6.5 Message Recording	5, 3, 2	80, 75, 60	10, 5, 5	1980, 1980, 1978	10, 5, 3	0.35, 0.175, 0.075

*Upper Quartile, Mean, Lower Quartile

eased for the video movie library if one used a store-and-forward mode of transmission and a video tape recorder. This would trade a decrease in bandwidth costs for an increase in terminal costs, and the total cost of the system would probably be increased. Calculations based on Table 5.2 will allow us to make more quantitative comparisons.

Table 5.2 gives estimates of single transaction duration in minutes, the percent of the transaction time required for data transmission, the average number of transactions per month for each subscriber to the service, a median estimate of the most likely year in which the service will be introduced in the United States on a mass basis, the percent penetration of all U.S. households five years after the service is introduced in the United States on a mass basis, the percent penetration of all U.S. households five years after the service is introduced, and the value of the service after five years in dollars per month. Median and upper and lower quartile values have been quoted for each estimate. The median value is underlined. (Since the data represents only a few responses and their distribution is often asymmetric, the median and quartiles are probably more reliable measures of central tendency and dispersion than the mean and standard deviation).

We expect that the estimates in Table 5.2 will be more reliable to the extent that they depend upon technological factors rather than economic political, or cultural factors. Thus, one might assume that the percent of a transaction devoted to data transmission is more reliably estimated than the year in which service would be initiated in the United States on a mass basis. The order of the estimates in Table 5.2 corresponds roughly to that of increasing dependence on social factors. Nonetheless,it is very instructive to estimate the potential costs and revenues for the aggregate of these services as a function of time. Baran has performed such a calculation based on the panel's median estimates for year of introduction and the value of service five years after introduction*. (In making this calculation he made the simplifying assumption that the growth of each new service will follow an exponential growth law "from the time of introduction to the fifth year thereafter with the exponent corresponding to a doubling of revenues in each of the first five years." In every year after the fifth, he assumed that the service's rate of growth would be halved.)

5.3 Deriving Traffic Estimates from Baran's Data

The traffic for a particular service is the number of subscribers using that service during a given period. Baran supplies estimates for the percentage of households subscribing to each service (Characteristic 7) and the average number of transactions per month for each subscriber (Characteristic 4). The product of Characteristics 4 and 7 with the assumed number of households gives the total number of transactions per month for the service in question. Assuming that the requests for service occur randomly, one can derive the number of transactions per hour by multiplying the number per month by the number of hours per month the system is in use. Multiplying the number of transactions per hour by the duration of the transaction in hours (Characteristic 2) gives the traffic for that service. The assumptions we have used in

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*This seems reasonable as a first approximation. However, checking the results for Service 1.1 (Video Library) we note that the median time of introduction is 1980 and 10 percent of the households will be served by the service in 1985 (five years after introduction). Since the value (price) of the service is assumed to be 1.50\$/month, the anticipated yearly revenue would be:

$$1.50 \times 12 \times 0.1 \times N$$

where N is the number of households in the United States. The yearly revenue listed in Table A-1 of the Baran report is 1.8×10^9\$ corresponding to $N=10^9$. This seems high! If we assume 10^8 households by 1985, the yearly revenue would drop to 180×10^6\$.

deriving the traffic are discussed below in more detail.

We will generalize Baran's results in two ways. First, we have considered the *type of display* which a particular service requires. Second, we have indicated the extent to which the service requires *two-way communication*. Translating these requirements into bandwidth requirements, allows us to estimate the total bandwidth which must be reserved to supply a particular service.

Similar considerations apply to any telecommunications network. For example, each telephone line terminating in a subscriber location has an available bandwidth of approximately 2 KHz[5-9]. However, telephone usage patterns are such that approximately 1/10 of the lines are active in the busiest time period. Thus, a private telephone line represents an effective individual bandwidth of 2 KHz/10 = 200 Hz. This is reflected in the design of telephone systems which need only enough equipment to serve 1/10 of the subscribers at any time.

A parameter of equal importance in telecommunications system design is the time taken by a particular transaction. Three minutes is a reasonable average holding time for a telephone call[5-10]. The average holding time t in hours multiplied by N, the average number of requests in a one hour period gives the request rate (a) in call-hours (Erlangs). $a = Nt$ defines the traffic load on a telephone system.

The traffic load on a FDM BCN differs significantly from that on an SDM telephone network. In an SDM network each subscriber is always connected to a fixed bandwidth channel. In an FDM network such as a conventional CATV system the total bandwidth is shared in common by all the subscribers. Since the total bandwidth is limited, it would be desirable to supply the subscriber with the minimum bandwidth necessary for his particular communications requirement. This suggests that BCN traffic should be represented by $T = N t B$ where N = average number of requests/hr., t = average transaction time in hours and B = average bandwidth requested.

To carry out similar calculations of aggregate system requirements based on Baran's estimates of demand, the number of transactions per month for each subscriber has to be converted to the number of requests/hour and an estimate must be made of the bandwidth required to perform the service.

The number of requests/hour is proportional not only to the number of transactions per month, but also to the number of subscribers using the service and the number of hours during the month when the service is used. We need to estimate the peak traffic since the cable system will have to accomodate it. We know that the system will not be used uniformly over a 24 hour period. Since the interative services we are considering could be offered over a telephone line if it had sufficient bandwidth, we will want to consider both telephone and television statistics when estimating the traffic.

Figures 5.1 and 5.2 indicate the hourly variation in telephone and broadcast television usage. Figure 5.1 indicates the difference in telephone traffic for central offices serving business and residential areas. Both businesses and residences follow a bimodal distribution with business traffic peaking between 10 and 11 in the morning and 2 and 5 in the afternoon. In the home there is an evening peak between 7 and 8. Figure 5.2 indicates that "the television audience rises steadily through the morning and then remains fairly level until late afternoon. At this point, with the children home from school and play, set usage starts to rise again. It reaches a peak between 8 and 11 PM, then drops sharply"[5-11].

Comparison of Figures 5.1 and 5.2 indicates not only the non-uniformity of telecommunications usage, but also the marked difference between the two media. Some indication of the difference is the fact that television is watched primarily for entertainment and secondarily for information. (A survey of New York television programming in 1954 indicated that 78 percent of the time was devoted to entertainment and 22 percent to information.[5-12]) The telephone on the other hand is used for a variety of request-oriented tasks such as shopping, information, and business transactions.

The composition of the television audience varies during the day. As one might expect, women and children dominate viewing in the morning, children and teenagers dominate late afternoon viewing, and the entire family watches television in the evening. This could significantly affect the demand for interactive cable services. It indicates that particular services appealing to men, women, or youth will be in more demand during certain periods of the day.

Although television usage varies significantly on an hourly basis, it varies less on a daily basis. Table 5.3 below indicates the extent to which weekend use differs from weekday use. Telephone statistics indicate even less daily variation in traffic [5-14].

Table 5.3 Percentage of "In-Home and Awake" Time
Average TV Set Owner Spends with TV [5-15]
(WHAN Survey, Iowa, 1954)

	Weekdays	Saturday	Sunday
Men over 18	34%	30%	17%
Women over 18	29	24	32
Youth, 12-18	43	40	55
Children, 4-11	43	33	51

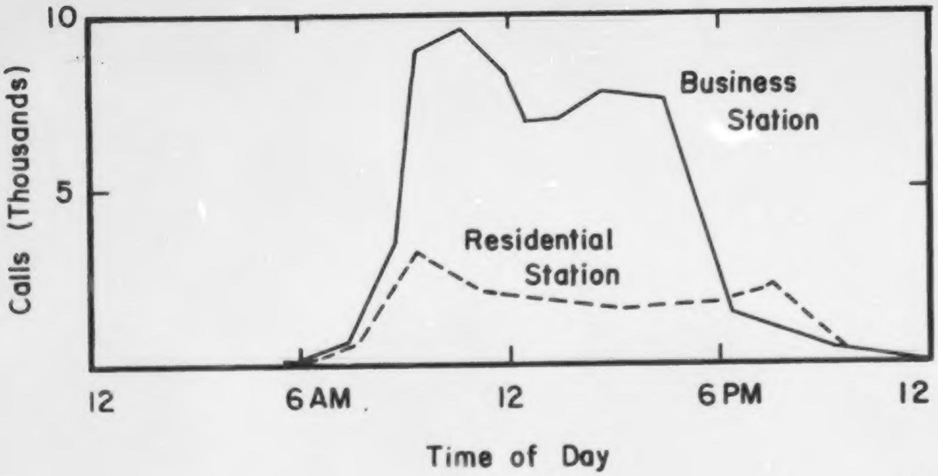

Fig 5.1 Telephone Usage[5-10]
Hourly Variation in Residential and Business Calls

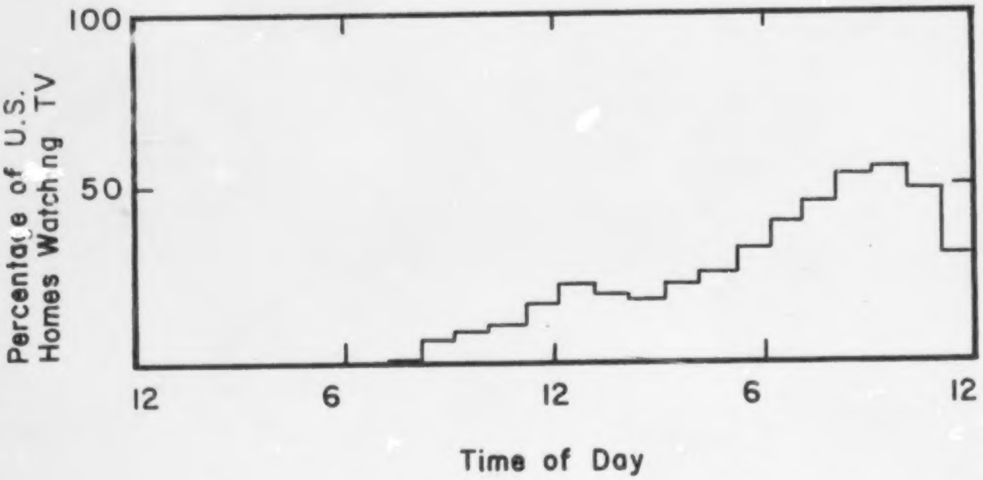

Fig. 5.2 Television Usage[5-13]
Hourly Variation in TV Viewing (January 1957)

From Table 3.3 it is clear that television viewing consumes a major fraction of available time in the home. However, the extent of usage varies significantly between households as indicated by the histogram in Figure 5.4. A similar variation is found with telephone subscribers and is shown in Figure 5.5.

The above data on telephone and television usage suggests that Baran's estimates of demand for interactive services need to be treated with caution. Baran made no estimates of Who would use the service When, although this would have a significant effect on traffic patterns. Baran's data does not estimate the interaction of new services with traditional telephone and television usage, although one would expect significant changes*.

The patterns of telephone and television traffic are significantly different. Television tends to be watched continuously for long periods. (A Nielson survey indicated that 49 percent of the audience for one evening television program came directly from the preceding show on the same network. This high degree of viewer inertia is well known to broadcast networks and taken into account when scheduling programs.[5-18]) Telephones, on the other hand, tend to be used continually for short periods. Baran's estimates of single transaction durations (Table 5.2) indicate that interactive cable services will tend to behave like telephone traffic. However, in the case of services such as the Video Library, holding times may be very long.

5.4 Traffic Estimates for Broadband Communication Networks

In this section we translate estimates of the need for telecommunication services into performance requirements for broadband telecommunication systems. As we have seen in Section 5.3, there is a wide variation in the calling rates and holding times for individual subscribers. These statistical distributions are the basis of traffic theory.

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*Actually, Baran's study did ask what medium was likely to provide the service. However, these responses have not been published.

One could design a telecommunications system to accomodate the maximum possible traffic. Such a system would have a large excess capacity and much of the equipment would be idle most of the time. Communications system designers use traffic theory to provide a desired level of service with a minimum capital investment. This means that some calls or requests may not be answered (blocked) or may be delayed. Traffic theory specifies the number of channels required to provide blocking probabilities or delay times below some specified level. In Section 5.3 we suggested that the use of interactive cable services was likely to follow the patterns of telephone use. Telephone traffic is characterized by the fact that subscribers call at random times and stay on the telephone for varying lengths of time. (We can express this more technically by saying that calling times follow a Poisson distribution. Holding times are distributed either exponentially or are nearly constant. As far as the probability of blocking is concerned, it appears to make little difference whether an exponential distribution or a constant holding time is assumed. Delay probabilities, however, are critically affected by which is assumed. The nature of the distribution is significant since communication systems must be designed to accommodate some maximum variation in system use instead of the mean usage).

The cable system will have to accommodate some maximum variation in interactive service traffic. We will assume that each service makes an independent contribution to the total traffic, that each can be represented by a constant transaction time, and that the request rate for each service follows a Poisson distribution. Since we are dealing with home usage we assume that

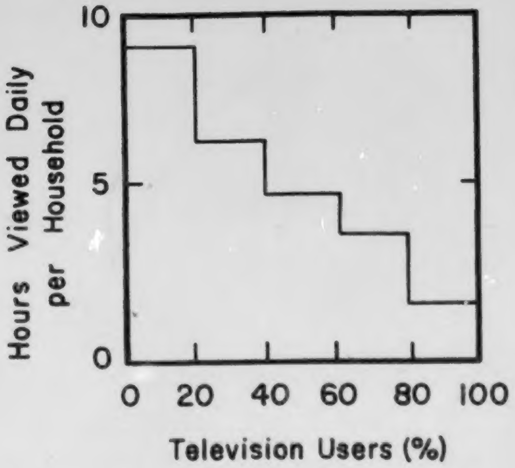

Fig. 5.4 Variations in Television Usage[5-16]
A.C. Nielsen, April 1955

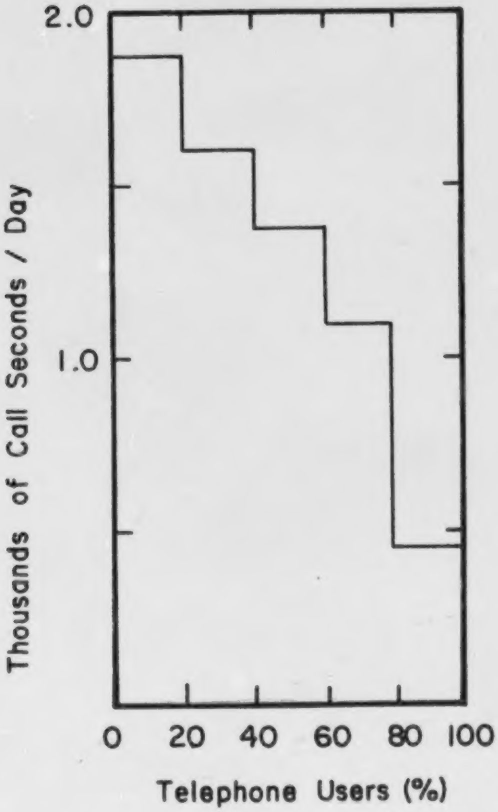

Fig. 5.5 Variations in Telephone Usage[5-17]

requests occur randomly in a 12 hour period between 9 AM and 9 PM. This approximately covers the time period shown in Figures 5.1 and 5.2 of high telephone or television usage. We further assume that each month has 30 days so that 100 subscribers making an average of 20 interactive transactions per month represents an average of:

$$\frac{100 \times 20}{30 \times 12} = 5.6 \text{ calls/hour.}$$

If each transaction takes 30 minutes the total traffic is

$$a = \frac{5.6 \times 30}{60} = 2.8 \text{ Erlangs}$$

Using the Poisson Formula eight channels would be sufficient to accommodate 100 subscribers 99 percent of the time. If only six channels were available, the 100 subscribers would be unable to use the service 10 percent of the time. This would probably be unacceptable for most services. If 1000 subscribers were to be accommodated, 45 channels would be needed to ensure 99 percent probable service. (Note that the number of channels needed to maintain service rises more slowly than the number of subscribers to be served.)

Table 5.4 translates the median demand forecasts for each service listed in Table 5.2 into Erlangs per subscriber. If t = single transaction duration in minutes and n = average number of transactions per month,

$$a = \frac{nt}{30 \times 12 \times 60} = \frac{nt}{2.16 \times 10^4} \text{ Erlangs/subscriber}$$

To calculate the total traffic, the values in Table 5.4 need to be multiplied by the number of subscribers. The percent of penetration of all U. S. households five years after introduction can be used to make relative estimates. Since this is an estimate for all U. S. households, however, the percentage should be higher for any particular cable system.

Table 5.4: Traffic Requirements for Interactive Services

Service	Traffic Load/Subscriber (10^{-3} Erlangs)	Service	Traffic Load/Subscriber (10^{-3} Erlangs)
1.1	37	5.1	28
1.2	1.0	5.2	6.9
	0.7	5.3	0.9
2.1	14		
2.2	14	6.1	2.3
2.3	2.3	6.2	2.8
2.4	2.3	6.3	1.8
2.5	1.2	6.4	4.6
2.6	0.7	6.5	0.7
2.7	1.4	Total	217.3
2.8	0.3		
2.9	1.2		
3.1	30		
3.2	14		
3.3	18		
3.4	18		
4.1	1.4		
4.2	2.3		
4.3	2.3		
4.4	3.5		
4.5	1.4		

5.5 Required Bandwidth Estimates for Broadband Communication Networks

This section uses the traffic estimates of the preceding section to determine the downstream and upstream bandwidths necessary for a BCN to supply these services. Before this can be done one needs to estimate the bandwidth required to deliver a particular service.

Table 5.5 estimates the terminal requirements for the list of 30 services we have been considering. In many cases a lower quality of service might be adequate. For example, Service 1.3 (Restaurant Information) could be sent over a fixed font alphanumeric data channel. However, it may well be that successful marketing of the service would require higher quality. Thus, we have suggested an image quality comparable to that of a typewritten page.

In some cases, marketing considerations might dictate that a full color film clip would be advisable. This would require a video channel. In other cases, our choices are not entirely consistant. Including still photographs in Service 2.1 (Electronic Newspaper) would require somewhat slower delivery, wider bandwidth, or more data compression than we have assumed for high quality facsimile transmission. This has been indicated by using the symbol F*.

In many cases tradeoffs need to be made to assure an adequate display. For example, we are centainly accustomed to seeing movies on conventional television sets. However, present video displays leave something to be desired for instruction where one often wishes to examine written material. Services 6.3 and 6.5 (answering services and secretarial assistance) are more conventionally associated with the telephone network than a cable television network. Baran's study, in fact, left open the question of who would supply the services.

The most important conclusion to be drawn from Table 5.5 is that the bandwidth of a video channel is not needed to provide almost all of the interactive services Baran has proposed. On the other hand, bandwidths larger than those presently available on the telephone network would be needed. Service 1.1, the Video Library, will place the most severe demand on the system because a moving picture display is needed. (Note that remote scanning of books in a library (Service 2.4) can be accommodated with a facsimile channel.) To take advantage of lower bandwidth requirements, however, a terminal more sophisticated than a conventional television set would be required. It remains to be demonstrated whether this would result in a lower system cost as discussed in Section 2.7.2.

Since we are dealing with interactive services the return bandwidth needs to be specified as well. Since one usually needs to transmit only

Table 5.5: Terminal Requirements for Interactive Services

Service	Format	Resolution and Capacity	Downstream Bandwidth
1.1	MP	PH	V
1.2	LD	TW	F
1.3	LD	TW	F
2.1	SP	PP	F*
2.2	SP	PP	F*
2.3	LD	TW	F
2.4	SP	PP	F*
2.5	AN	TT	D
2.6	LD	TW	F
2.7	LD	TW	F
2.8	LD	TW	F
2.9	AN	TT	D
3.1	LD	TW	F
3.2	LD	TW	F
3.3	MP	PP	V
3.4	LD	TW	F
4.1	AN	TT	D
4.2	LD	TW	F
4.3	SP	PP	F*
4.4	SP	PP	F*
4.5	LD	TW	F
5.1	LD	TW	F
5.2	LD	TW	F
5.3	LD	TW	F
5.4	LD	TW	F
6.1	LD	TW	F
6.2	SP	PP	F*
6.3			A
6.4	LD	TW	F
6.5			A

Key

Display Format(Table 2.7)

MP - Motion Picture
SP - Still Picture
LD - Line Drawings or Variable Font Writing
AN - Fixed Font Alphanumeric

Resolution and Capacity (Table 2.8)

PH - Photographic
PP - Printed Page
TW - Typewritten Page
TT - Teletype Message

Downstream Bandwidth

V - Video (4MHz)
F - High Quality Facsimile (50KHz)
A - Audio (4KHz)
D - Data (1KHz)

instructions to the head end, a data channel is adequate in most cases. In addition, services will need to be routed or addressed to a particular subscriber and in some cases information will need to be processed before it is sent to the subscriber. Table 5.6 indicates return channel and message control requirements imposed on the cable system by particular services.

A "D-" in Table 5.6 indicates that a signal need to be sent over a return channel only to initiate the service. Continuing use of the return channel is not required. In cases where the answer is ambiguous we have assumed continuing use of the data channel. For example, if a large Calendar or Restaurant List is to be searched, the return channel will need to be used on a continuing basis (D). If, on the other hand, one wishes to see the menu for a known restaurant, a single request for information (D-) would be sufficient. If one then wishes to reserve a table, continuing use (D) would be required.

From Table 5.6 we see that most of the services can be provided with a simple data entry device such as a Touch-Tone type of telephone. In only two cases was a larger bandwidth channel needed to provide the service. Thus we anticipate that return channel requirements will be small for the services we are considering!

All of the services will require message routing so that they can be addressed to a particular subscriber. Over half (16) require the manipulation or regular updating of data. To satisfy these requirements a computer must be included in the system which will allow both the routing and processing of messages.

Table 5.6: System Requirements for Interactive Services

Y = Yes, N = No

Service	Reverse Channel Bandwidth	Message Routing Required	Message Processing Required
1.1	D-	Y	N
1.2	D	Y	N
1.3	D	Y	N
2.1	D-	Y	N
2.2	D	Y	Y
2.3	D	Y	Y
2.4	D	Y	N
2.5	D	Y	N
2.6	D-	Y	N
2.7	D	Y	N
2.8	D	Y	N
2.9	D	Y	Y
3.1	D	Y	Y
3.2	D	Y	Y
3.3	D-	Y	N
3.4	D	Y	Y
4.1	D	Y	Y
4.2	D	Y	N
4.3	D	Y	Y
4.4	D	Y	Y
4.5	D-	Y	N
5.1	D	Y	Y
5.2	F	Y	Y
5.3	D	Y	Y
5.4	D	Y	Y
6.1	D-	Y	N
6.2		Y	N
6.3	D-	Y	Y
6.4	F	Y	Y
6.5	D-	Y	Y

We have combined these estimates of bandwidth requirements for particular services with Baran's estimates of the rate at which these services are introduced [5-20, 5-21]. The result is an estimate of the growth of bandwidth requirements in interactive cable networks. Since the estimate represents an aggregate of all the service requirements, it is likely to be more dependable than the estimate for any particular service. Traffic is measured in Hz-Erlangs. This is the average bandwidth that would have to be supplied continuously to every subscriber to meet the aggregate demand for interactive services.

In summary, we find that Video Library Service and other monomedia video uses would require (100, 220, 300) KHz per subscriber of a downstream bandwidth in a mature system. (100, 220, and 300 KHz are lower quartile, median, and upper quartile estimates, respectively.) Since a single coaxial cable has approximately 200 MHz of available bandwidth, an FDM system would be able to serve only a thousand subscribers even if all of its bandwidth could be devoted to interactive services. In 1972 the average cable television system served 2500 subscribers. It could not supply this projected demand without laying additional cable.

The bulk of the bandwidth is used by two services; the Video Library and Televised Instruction (Services 1.1 and 3.1). All of the remaining services together require only (4, 8, 20) KHz per subscriber. The bandwidth of two or three video channels would be able to supply them to a thousand subscribers. The bandwidth needed is proportional to the number of subscribers. The bandwidth of twenty or thirty video channels would be required to supply these services to ten thousand subscribers. All of this assumes ideal dynamic allocation. A less efficient allocation scheme would require several times the bandwidth.

This raises a fundamental System Design issue. To accommodate possible growth in interactive services, definite limitations need to be set on the number of subscribers served by a single headend or distribution center. This would allow the expansion of interactive services without the necessity of rebuilding the cable distribution network.

The above estimates suggest that interactive services could be accommodated easily in a 3000 subscriber FDM single-cable network. (This excludes monomedia video services such as the Video Library. To accommodate these, FDM networks would need to be limited to a thousand subscribers.) Headend costs are a small fraction of distribution system costs; approximately 7% for a 3500 subscriber system (Table 3.2). Thus, cable distribution networks should be designed to accommodate installation of additional distribution centers as the demand for interactive services increases.

REFERENCES

5-1 P. Baran, "Potential Market Demand for Two-Way Information Services to the Home, 1970-1990," Institute for the Future,Report R-26, Dec. 1971.

5-2 P. Baran, "30 Services That Two-Way Television Can Provide," THE FUTURIST, p. 202, October 1973.

5-3 P. Baran, "Broad-Band Interactive Communication Services to the Home: Part I - Potential Market Demand," IEEE Transactions on Communications, COM-23, 5 (1975).

5-4 M. V. Jones, "The Social Impact of Interactive Television," IEEE Transactions on Communications, COM-23, 1156 (1975).

5-5 T. J. Gordon and O. Helmer, "Report on a Long Range Forecasting Study," Paper P-2982, The RAND Corporation, September 1964.

5-6 Olaf Helmer, "Analysis of the Future: The Delphi Method," Paper P-3550, The RAND Corporation, March 1967.

5-7 Norman C. Dalkey, "An Experimental Study of Group Opinion: The Delphi Method," Futures I, 408-426, September 1969.

5-8 B. Brown and O. Helmer, "Improving the Reliability of Estimates Obtained From a Concensus of Experts," Paper P-2986, The RAND Corp., Sept. 1964.

5-9 R. W. Lucky, IEEE International Convention Digest, p. 442. 1967.

5-10 American Telephone and Telegraph Company, "Switching Systems," 1961.

5-11 L. Bogart, "The Age of Television," Fredrick Ungar Publishing Co., New York, p. 75, 1958.

5-12 L. Bogart, op. cit., p. 57.

5-13 L. Bogart, op. cit., p. 77.

5-14 American Telephone and Telegraph Company, op. cit., p. 93.

5-15 L. Bogart, op. cit., p. 74.

5-16 L. Bogart, op. cit., p. 69.

5-17 American Telephone and Telegraph Co., op. cit., p. 97.

5-18 L. Bogart, op. cit., p. 81.

5-19 American Telephone and Telegraph Co., op. cit., Figure 3-A.

5-20 T. E. Everett, R. J. Gutmann, and K. Rose, "The Impact of Two-Way Interactive Communication on Cable TV Systems," presented at the National Telecommunications Conference, New Orleans, December 1975.

5-21 T. E. Everett, "A Computer Simulation of Braodband Cable Communications System Design; Part B: Traffic Loading and Terminal Requirements," M. S. Thesis, Rensselaer Polytechnic Institute, May 1975.

6. ISSUES

In this chapter we consider several issues raised by the development of cable television technology. We have limited our discussion to twelve technical issues which relate to the possible evolution of broadband communication networks. These were issues which we could discuss on a relatively firm technical or economic basis. One less technical issue--the impact of BCN development on education--is included among the twelve.

We have likewise restricted our attention to the immediate consequences of technological decisions. The influence of communications on the social fabric is a complex and controversial subject well beyond the scope of our study. We have considered changes which the development of broadband communications technology could make in modes of communication. However, we considered that the possible effects of those changes on the social fabric were too speculative to warrant discussion.

- Interactive Cable Television or Videophone

The Issue: Should interactive services be supplied by upgrading cable television systems or the telephone network? In many cases these services could be supplied by either system, provided appropriate modifications are made.

Background and Trends: At present neither system is a viable broadband communications network. Cable television lacks BCN capability because one cannot "place calls", i.e. individual subscribers cannot dynamically allocate or reserve channels. The local telephone system lacks BCN capability because it does not provide enough bandwidth to send video messages. Cable television systems are moving toward BCNs by providing two-way capability and leasing channels. Telephone systems are moving towards BCNs by providing the videophone as a broadband telecommunications service. Neither of these developments has established a viable market to date.

Which system is best suited for providing interactive services depends very much on the traffic characteristics expected for these services. Telephone systems are designed for individual, point-to-point communication over short time periods on the order of minutes. On the other hand, cable television systems are designed for mass distribution of programs for long time periods on the order of hours. Most proposed interactive services involve relatively brief communications to individual subscribers.

Neither the telephone nor cable television system can replace the other. However, it is likely to be much less expensive to provide for the dynamic allocation of channels on a conventional (FDM) cable television system than to replace the telephone distribution network with a broader bandwidth network.

Several technological developments could shift these trends. Four are indicated below.

The use of Optical Fibers in telephone distribution systems would provide broadband capability. The incorporation of integrated circuit memory units in Television Terminals would allow telephone lines to transmit the data for interactive alphanumeric displays. Alternatively, cable television networks could become the preferred means for digital data transmission on a local level. Installation of an SDM cable television system instead of a conventional FDM system would simplify the dynamic allocation of channels.

The impact of these four trend-shifting developments are discussed later as individual issues. Telephone and cable television systems are compared in Section 2.2. The traffic characteristics expected for interactive services are discussed in Chapter 5. The costs of distribution and control are discussed in Section 3.2. Regulatory constraints are discussed in Section 3.3.

Present Policies and Alternatives: Present policies tend to restrict the entry of telephone companies into cable television while requiring increased common carrier capability for cable television systems. Broadcasters, on the other hand, are allowed less restricted entry into cable telephone ownership.

The development of broadband communication networks would be enhanced by encouraging diversity in local distribution technology and compatibility in interconnect technology. Permitting some telephone system operators to integrate cable television with telephone services would encourage both local diversity and interconnect compatibility. Incentives for the installation of novel distribution technologies in new communities or apartment complexes would also encourage the development of alternative technologies. If alternative technologies are not encouraged, cable television systems are likely to remain fixed in technologies which will limit their capacity to become broadband communications networks.

● One-Way or Two-Way Services

The Issue: How much return bandwidth should cable television systems provide for communication from the individual subscriber? Present cable television systems are almost entirely one-way, with some provision made for return bandwidth to provide proposed interactive communications services. At the other extreme, two-way, point-to-point video communication between individual subscribers require as much bandwidth in the reverse direction as in the forward direction.

Background and Trends: At present, the most common provision for two-way transmission is the use of subsplit coaxial cable which allows upstream transmission over a 25 MHz bandwidth. Fortunately, most proposed interactive services require only a limited upstream transmission capability. Our estimates indicate that a subsplit system would allow sufficient upstream transmission capability for a 3500 subscriber system providing a wide range of interactive services. (This has not considered any services which would require video monitoring or two-way video communication.)

Two-way transmission requirements are discussed in Chapter 5.

Present and Alternative Policies: Two-way transmission is essential for the development of interactive services. However, in the absence of significant demonstrations of demand for video return or two-way video communication, present regulatory provisions appear to be adequate for service users. More upstream channels could be required to accommodate service suppliers. At this time, one should probably avoid requiring extensive return bandwidth, since provision for two-way, point-to-point video communication capability between all individual subscribers would require very much more bandwidth than present or contemplated cable systems are capable of supplying. Moreover, there is little known demand for such capability and needs should be established (via market studies and pilot projects) before any serious attempt is made to provide them.

- Expensive Terminals or Shared Facilities

The Issue: To what extent will access to cable communications services require terminals which are significantly more expensive than conventional television receivers? Alternately, to what extent can the cost of terminals be reduced if expensive facilities are shared by a large number of subscribers?

Background and Trends: Cable television was developed in this country when television dealers provided a distribution network to improve reception and increase their sales of television sets. Thus, by and large, dealers provided that distribution system and central (headend) facilities which cost the least to provide acceptable service. This trend has continued. Cable system operators have an immediate incentive to minimize their investment in a distribution system and central facilities. Television terminal manufacturers have an incentive to market more expensive terminals to provide increased capabilities.

Since television manufacturers generally do not operate cable television systems, there has been relatively little incentive to minimize total system cost. Since cable television operators do not derive significant revenue from interactive services, they have little incentive to supply facilities for them.

Total system cost can be reduced by trading terminal costs for shared central facilities wherever possible. The cost of providing a service to an individual subscriber is increased by at least the increase in terminal costs. The cost of centralized facilities to an individual subscriber is reduced in proportion to the number of subscribers. Thus, increased emphasis on centralized facilities should lower total system costs, making it economical for more people to use the services they provide.

Terminal capabilities are discussed in Section 2.5. A hierarchy of system requirements is outlined in Section 2.3.

Present and Alternative Policies: Present policies tend to separate the suppliers of terminal equipment from the renters of distribution facilities. To date, this has been reasonable since conventional television receivers could make maximum use of available cable services. This issue will become more critical as expanded cable services (e.g. more channels) require modified terminals (e.g. converters).

Present policies provide little incentive to lower total system costs by trading off terminal costs for central facility costs. Since telephone system operators generally supply telephone handsets as part of the telephone service, they are most accustomed to considering total system costs. Thus, permitting the integration of telephone and television distribution systems would tend to correct the present bias toward expensive terminals. The policy alternatives discussed under Interactive Cable Television or Videophone are equally relevant here.

- Computer Access

The Issue: To what extent should cable television systems be tied to computer systems and used for the local distribution of computer and digital data services?

Background and Trends: To date, relatively little work has been done on the incorporation of computers into cable television systems. MITRE's TICCIT system in Reston, Virginia coupled telephone line data return with computer generated cablecast displays. However, most proposed interactive services require a computer to process messages; all of them require a computer controller to route messages to individual subscribers and bill them for services. In addition, cable television channels are far superior to telephone channels for the transmission of digital data.

The requirements of interactive services for computers are discussed in Section 5.5. Cable television and telephone channels are compared in Section 2.4. Methods for supplying data channels for interactive services are considered in Section 2.6.

Present Policies and Alternatives: Little if any policy presently exists governing the integration of computers with cable television systems. Policies which encourage the use of cable television channels by suppliers of data services would probably provide a reasonable incentive for the growth of computer access. Alternatively, test projects for the development and demonstration of data services would also encourage computer access.

- Frequency or Space Division Multiplexed Distribution Networks

The Issue: Should cable distribution networks be frequency division multiplexed (FDM) like broadcast television, or space division multiplexed (SDM) like the local telephone system? The issue is important because these technologies are incompatible and competitive.

Background and Trends: Both distribution technologies have demonstrated technical and economic viability. SDM systems offer some advantages for the development of flexible, high capability BCNs. However, the vast majority of present cable television systems in this country are FDM. The tradeoff between FDM and SDM involves the tradeoff between expensive terminals and shared facilities discussed in the previous section. SDM distribution networks are more expensive to construct but can provide a wider range of serivdes with less expensive terminals than FDM distribution networks.

FDM and SDM technologies are defined and discussed in Sections 2.2 and 2.4. FDM and SDM costs are compared in Section 3.2.

Present Policy and Alternatives: Present policy does not explicitly favor a particular mode of distribution. Thus, in the absence of explicit incentives the present trend of FDM distribution is likely to continue. In view of the prevailing trends, it would seem prudent to place primary emphasis on upgrading FDM systems to provide interactive services. There are two reasons for this. First, the vast majority of present CATV systems are FDM; the cost of converting them to SDM would exceed the original installation cost. Second, although SDM systems may have greater ultimate channel capacity, our estimates indicate that FDM systems can be modified to meet the demand for the next ten years.

The superiority of SDM systems for high communications traffic suggest that their further development should be encouraged. Trial installations of such systems in new communities (Dennis Port, Massachusetts) or organizations (Case Western Reserve Medical Center) have been quite successful. However, there has apparently not been enough financial backing to encourage their significant deployment. Because such systems are more compatible with telephone technology, allowing telephone company ownership might lead to further developments along these lines.

- Frequency or Time Division Multiplexed Channels

The Issue: Should communication services share the same bandwidth by assigning them to different frequencies (FDM) or different time slots (TDM)? Which technology will provide the most efficient use of the spectrum (the largest number of communication channels) at the least cost? (This assumes an FDM distribution network. Efficient use of the spectrum is not an issue with an SDM distribution network.)

Background and Trends: Both TDM and FDM have been used to share data services. Our analysis indicates that a combination of FDM and TDM would provide the most efficient use of the spectrum at the least cost. Specifically, TDM should be used to combine digital channels with data rates less than 10 kbps (kilobits per second); FDM should be used to combine analog signal channels with bandwidths above 1 to 10 KHz and to combine digital signal channels with data rates above 10 kbps.

FDM and TDM technologies are discussed in Section 2.4. The use of these technologies for supplying data channels is considered in Section 2.6.

Present and Alternative Policies: Both FDM and TDM technologies are well advanced; however, it seems premature to set standards. Work is needed to develop reliable, low cost methods for allocating FDM and TDM communication channels dynamically in response to individual subscriber requests. This is a necessary step in implementing interactive services. It would make many services feasible by minimizing the bandwidth they require.

- Terminal Technology

The Issue: What terminal technology should be used for the display of printed and graphic documents to the subscriber? How much of an addition would this be to a conventional television set?

Background and Trends: Most proposed interactive services involve the response of a subscriber to "printed" messages. Present television receivers provide limited resolution and require a full video bandwidth to display such messages.

Several alternative technologies have been developed for reducing the bandwidth requirements for displaying messages. All of these involve techniques for remembering the message once it has been sent so that the video channel can be released for other uses. (The television screen is presently designed to quickly forget what has been written on it so that it can display moving pictures.) Thus, a means must be found to rewrite the remembered message on the television screen.

One technique uses a video recorder onto which messages are recorded and from which messages can be played on the television screen. This device is called a "frame-grabber." (It is a more complicated and hence, more expensive device than one which simply plays back messages prerecorded on mass-produced video discs.) There are simpler and correspondingly less expensive alternatives. One would be to develop television tubes with variable persistence screens. Another is the use of a semiconductor memory to store a message and convert it to alphanumeric characters for display on a television screen. Although this last technique is limited to fixed font alphanumeric messages, it is the least expensive addition to present television terminals.

All of the above alternatives would not improve the limited resolution available with conventional television sets. Present facsimile technology could be extended to display documents at reading speeds with resolutions comparable to those of a printed or typewritten page. In sufficient volume, displays without hard copy capability could probably be developed which would cost about as much as a conventional television receiver.

Terminal technology is discussed in Section 2.5. The possible development of facsimile technology is considered in Section 2.7.

Present and Alternative Policies: There is little in the way of general policy guidelines regarding terminal attachments to cable television systems. Our review of technological alternatives suggests that it would be premature to impose regulation.

Most attention has been focussed on the development of additions to conventional television receivers to allow them to supply interactive services. The potential attractiveness of facsimile technology as an alternative to conventional television displays suggest that it might be appropriate to support its further development.

- Video Library

The Issue: Should encouragement be given to the development of services for providing video programs which individual subscribers could view at their convenience?

Background and Trends: This service would be perceived by the subscriber as a natural extension of existing video programming. Available evidence indicates that the market for such a service would be large and immediate, both in the area of education and as an extension of present entertainment services. However, implementation of such a service on an extensive level in an FDM system would require a much larger accessible bandwidth than most present systems could provide. The growth of such a service could probably be accommodated more easily in an SDM system.

The bandwidth requirements and popularity of this service are analyzed in Chapter 5. The relative capabilities and costs of FDM and TDM systems are analyzed in Sections 2.4, 2.6 and 3.2. The use of video library services in education is considered in Section 4.2.3.

Present and Alternative Policies: Cable television systems being constructed under present regulations would be able to supply this service to only a small fraction of their subscribers. To accommodate all subscribers, cable systems would need to be designed so that fewer subscribers were accommodated by a single central facility. Thus, an FDM cable system serving 10,000 subscribers with single cable service would require 10 central facilities linked by trunk cable. Alternatively, triple cable service would require only three central facilities to serve 10,000 subscribers. The relative popularity of this service suggests that experiments in providing these services should be encouraged.

- Single or Multiple Cables

The Issue: How many FDM cables should be installed to service each subscriber? (FDM and SDM distribution networks differ. Multiple cables, one or more cables per subscriber, are inherent in an SDM distribution network.)

Background and Trends: Until recently, FDM systems were installed with only a single cable to serve all subscribers. Several more recent FDM systems are laying two cables to supply an anticipated demand for bandwidth. Such systems should be sufficient to meet all demands for interactive services except for the video library, video monitoring, and two-way video communication. (This assumes that the system has facilities for the dynamic allocation of channels.)

The bandwidth requirements of various services are discussed in Chapter 5. Different distribution systems and dynamic allocation schemes are compared in Sections 2.4 and 2.6, respectively. Interconnection is considered in Section 2.8.

Present and Alternative Policies: Present policies appear to be adequate to provide services with moderate bandwidth requirements. Some experimentation in the accommodation of services with high bandwidth requirements should probably be encouraged. In the absence of such encouragement it is unlikely that broadband communication systems will be developed with these capabilities within the foreseeable future.

As was noted in discussing the previous issue, services with a greater bandwidth requirement can be accommodated on FDM distribution systems by either laying more cable or decentralizing headend facilities. More study is needed to determine the relative feasibility of various approaches.

Excess cable capacity can also provide an advantageous tradeoff between system and terminal costs. Thus, interactive systems such as MITRE's TICCIT system have generally used expensive terminals (incorporating a video tape recorder) to compensate for limited cable bandwidths.

- Copper Cables or Optical Fibers

The Issue: Should copper cables be replaced by optical fibers in cable television systems? This is actually an issue for all wired communication systems, and includes telephone networks in addition to cable television networks.

Background and Trends: Our studies indicate that the development of optical cables will not have a significant impact on FDM networks, which are in the mainstream of cable television. However, SDM networks such as the telephone network can become competitive to cable television in providing interactive services if upgraded with optical fibers. The wider use of optical cables could lead to significant savings in scarce materials and some savings in energy.

Optical communications technology is discussed in Section 2.7.

Present and Alternative Policies: The development of optical fibers (and other components of optical communication systems) is being aggressively undertaken by the telephone companies and the Department of Defense at the present time. These developments should be closely followed, since they could lead to radical shifts in the paths along which cable television may evolve. As optical fibers replace copper wire pairs, serious questions will be raised about the economic wisdom of present policies requiring the separation of telephone and television services.

- Interconnection by Ground Links or Satellite Transmission

The Issue: Should cable television systems be interconnected by ground or satellite transmission?

Background and Trends: Nationwide interconnection by satellite has been demonstrated and is economically competitive with more conventional microwave or cable links.

Substantial use of satellites for interconnection raises the question of tradeoffs between the use of two scarce resources: the limited frequency spectrum available for microwave broadcasting and the limited number of synchronous satellite orbits. High costs and a lack of video material have led to little interest in nationwide interconnection on the part of cable television operators. Either microwave or cable links are more attractive technologies for regional interconnection of local cable systems. Even though the technology exists, regional interconnection has proceeded slowly.

Interconnection is discussed in Section 2.8.

Present and Alternative Policies: The relative national priorities for the use of the electromagnetic spectrum have traditionally been matters of concern to the FCC. Relative national priorities for the use of synchronous orbits also need to be determined.

Since a regional interconnection offers the possibility of wider market support for interactive services, its development should probably be supported. The present marginal profitability of interactive services suggests that they will not develop without encouragement.

- Education

The Issue: What will be the impact of broadband communication networks on educational practice?

Background and Trends: If education is defined as certified instruction, it appears that television has had little direct impact on educational practice. Television has been demonstrated to be an effective educational medium. Moreover, most people spend a significant fraction of their time watching television. Nonetheless, television continues to play a minor, supplemental role in classrooms. The availability of broadband communication networks offers new possibilities (interactive programming such as educational games) but is unlikely to change the prospects for significant utilization. Significant use of video instruction would require major increases in the number of educational channels.

The impact of cable television on education is discussed more fully in Section 2.4.3.

Present and Alternative Policies: The role of BCN technology in education is only one facet of general educational policy. Significant alterations in present educational policies would be required for it to significantly displace classroom teachers. Some experimentation might be encouraged in situations where conventional instruction is unusually costly or ineffective. In any event, BCN technology can only be the vehicle for an educational program. One should remain skeptical of claims for the ability of BCN technology alone to provide significant innovations in educational practice.

Other issues were raised in the course of this study which were beyond its scope or financial constraints. These are certainly worthy of further investigation and would constitute significant studies in their own right. A list of ten such issues is included as Table 6.1. Other issues could probably be added to this list. In general, these issues are not unique to cable television. They would have to be addressed in a similar fashion in studies of other communications media. In particular, they would need to be addressed in studies of video telephones, computer networks, or data communications. The complex interrelatedness of present telecommunications technology makes it difficult to reliably isolate the consequences of a particular technological innovation.

Table 6.1 Issues for Further Study

1. Business Use. The use by business of interactive services and the implications of that use for the economic viability of these services.

2. Payment Alternatives. Economic Implications of different alternatives for payment by subscribers for interactive services. Alternatives to be considered would include rental, direct payment, inclusion in housing cost or rentals, advertising subsidy, and tax subsidy.

3. Privacy and Security. The implications of BCN technology for individual privacy and information security.

4. Copyright. The implications of BCN displays of printed information on copyright regulations.

5. Program Production. The costs and implications of widespread production and storage of materials for video distribution.

6. Urban Use. The technology, costs and potential usage of broadband communication services in densely populated urban environments. In particular, one would want to consider the possible benefits of utility corridors for supplying a multitude of services.

7. Transportation Implications. The use of telecommunication services to replace or supplement transportation requirements.

8. Elder Care. The use of BCN technology to provide increased services for the relatively immobile elderly.

9. Neighborhood Identity. The possibility of using BCN technology to provide interactive micromedia which could leak to a greater sense of community participation.

10. Propaganda and Information Control. The extent to which expansion of BCN technology would foster or inhibit the inclusion of erroneous images.

Appendix A FDM/SDM DISTRIBUTION SYSTEM DESIGN PROGRAM

A.1 Specifying the Grid Topography

The subroutine GRDTOP is used by both the FDM and SDM design programs to define the characteristics of the subscriber grid. These characteristics include the number of lots (N) situated on the side of a block (the long dimension), the number of lots (M) situated on the end of a block (the short dimension), and the location of utility poles on the block. The subroutine uses data supplied by the user, including lot width (LW), lot depth (LD), street width (SW), block width (BW), block length (BL) or the number of lots per block (NLPB), and the maximum and minimum allowable distances between utility poles (DMAX and SMIN), in addition to the simple assumption that the short dimension of the block (the block width) must be exactly twice the lot depth. Also, two practical constraints are utilized. The first requires that utility pole locations fall on the boundary between adjoining properties except perhaps on corner lots. The other constraint is that there be an integer number of uniform lots on the ends and sides of the blocks.

This subroutine is extremely flexible in that it allows the user to supply either the block dimensions or the number of lots desired on the block. Its power is reflected in its ability to accept input data that conflicts with the requirements of the idealized, regular, symmetric subscriber grid. The given parameters are altered by the minimum amount which will eliminate all the conflicts. In addition, suitable messages notifying the user of these changes in his given parameters are printed by the subroutine. Finally, the pole locations on the grid are calculated using realistic constraints.

A.2 Laying Out the FDM Distribution System

The FDM design program initiates its distribution system design by calling the subroutine GRDTOP and obtaining from it the parameters of the subscriber grid. Then the program obtains information regarding the hardware to be used in the design by calling in succession eight "equipment-selection" subroutines. Each of these subroutines provides such information as nominal signal output levels and nominal gains for amplifiers or decibel loss figures for cables and taps, as well as manufacturer, model numbers, usable bandwidths and both capital and labor costs for specific hardware items used in the design (such as trunk amplifiers, line-extender amplifiers, trunk cable, feeder cable, subscriber taps and attenuator pads). At the present time, the user must specify as data the specific equipment (and its associated parameters and information) to be used in the design. The "equipment-selection" subroutines read this data and transmit it to the main program. These subroutines could be adapted at a later date to allow selection of the most appropriate piece of equipment from a catalog of items having varying specifications and costs. However, such an equipment optimization was deemed not essential for the purposes of the current study.

Finally, the design program costs out the distribution system design and prints out the information including the equipment specifications, the per unit capital and labor costs, the number of each item required, and the total capital and labor costs and a cost summary. These totals for all the items required by the design are then summed, and the resulting total cost for the area is printed along with the total cost per subscriber (assuming 100 percent penetration).

A.3 Laying Out the SDM Distribution System

Like the FDM program, the SDM design program initiates its distribution system design by calling the subroutine GRDTOP and obtaining from it the parameters of the subscriber grid. Then the program obtains information regarding the hardware to be used in the design by reading data cards containing this information. Most of this information consists quite simply of the item's identification, model number, manufacturer, and both capital and labor costs for specific items used the design -- such as rack rack cabinets, power units, program selector switches, and crosspoint switches for the local exchange as well as Six-Quist distribution cable and Single-Quist drop cable. Six-Quist cable, manufactured by Rediffusion International Ltd., consists of six twisted pairs of wires for broadband communications and six pairs (of narrower bandwidth) for transmitting service request information from the subscriber control unit to the local exchange. Single-Quist has only one of each of these types of pairs. This data is not quite as detailed as that for the FDM program, largely due to the fact that additional parameters such as amplifier output levels and gains or decibel loss figures for the cables are not of primary concern for the SDM-type system. Instead, switching problems receive the bulk of the attention in SDM system designs.

The user must supply some data regarding the assumptions to be used in the switching system design. This data includes the following:

1. the requested blocking probability;
2. the percentage of the served subscribers using the service during peak traffic periods;

3. the average duration of a call;
4. the percentage of calls that are nonlocal; and
5. the number of subscribers in a subgroup.

The routine then calculates and prints out such information as the traffice figures, the number of Stage 1 and Stage 2 switch blocks, the number of nonlocal output circuits and local output junctors, and the number of cross-point switches required as well as the resulting blocking probabilities.

Following the switching system design, the simulation program costs out the distribution system design (including the local exchange itself) and prints out the information including the equipment identification, the per unit capital and labor costs, the amount or number of each item required, the total capital and labor costs, and a cost summary. These totals for all the items required by the design are then summed, and the resulting total cost for the area is printed along with the total cost per subscriber (assuming 100 percent penetration).

GLOSSARY

Analog Transmission - Transmission of a continuously variable signal as opposed to a discretely variable symbol. Bandwidth in Hz indicates the rate of information flow with analog transmission.

Bandwidth - The range of frequencies over which transmission is allowed in a channel or system. Alternatively, the difference expressed in Hertz between the upper and lower frequencies of a band.

BCN - Broadband Communications Network. A communications network with a capacity for the exchange of large quantities of information in both point-to-point and broadcast modes. This implies a bandwidth significantly greater than the approximately 3 KHz bandwidth characteristic of telephone channels.

Blocking Probability - The probability that a channel is unavailable, i.e., blocked.

bps - bits per second. A measure of the rate at which digital data is transmitted.

Broadcast - A communications system in which the message is transmitted through the atmosphere to any receiver within range.

Cablecast - A communications system in which the message is transmitted to any receiver connected to a cable distribution system.

Carrier - See Modulation.

CATV - Community Antenna Television. This is often popularly understood to stand for Cable Television.

Channel - That part of a communications system which connects a message source or transmitter to a message sink or receiver.

Coaxial Cable - Tubular, two-conductor cable in which the inner conductor is surrounded by an insulating sheath and a concentric outer conductor. This form of cable is a wide bandwidth (200 MHz) transmission medium.

Common Carrier - A public utility company that is recognized by an appropriate regulatory agency as having a vested interest and responsibility in furnishing communications services to the general public.

Computer Network - An interconnection of assemblies of computers, terminals, and communications facilities.

Crosspoint or Coordinate Switch - A switch which connects the input and a number of outputs by closing a single switching element. The input and output lines are generally arranged in rows and columns with the switching elements at the intersections (crosspoints).

Digital Transmission - Transmission of a discretely variable signal. Data rate in bps indicates the rate of information flow with digital transmission.

Downstream Transmission - Transmission of signals from the headend to the subscriber in a cable television system.

FDM (Frequency Division Multiplexing) - Division of the available frequency range of a given transmission medium into several narrower bands, each of which is used for a separate channel.

Filter - An electrical circuit which blocks the transmission of certain frequencies.

FM - Frequency Modulation, see Modulation.

Headend - The central point from which signals are distributed in a cable television system.

Holding Time - Average time of one message.

Hz - Abbreviation for Hertz or cycles per second, the conventional unit of signal frequency.

Midsplit - A two-way communications scheme for coaxial cable using the frequency range from 5 to 108 MHz for upstream transmission and 174 to 260 MHz for downstream transmission.

Modem - A contraction of "modulator-demodulator". A device for sending digital signals over analog transmission lines.

Modulation - A method of shifting the frequency of a signal by combining it with a high-frequency "carrier" so that the combined signal occupies a range of frequencies about the carrier frequency. If the signal is used to vary the frequency of the carrier, the modulation scheme is called frequency modulation.

Multiplexing - A scheme for combining several channels in one transmission medium. See FDM, SDM, and TDM.

Passband - A frequency range having specific upper and lower frequencies within which transmission takes place.

Pel - Acronym for a picture element. The smallest resolvable element of a picture.

Point-to-Point Connection - A network configuration in which a connection is established between two, and only two, terminal installations. (The connection may include a switching exchange.)

Resolution - The degree of detail discernable in a picture.

SDM (Space Division Multiplexing) - Association of each channel with separate cables, interconnected at a central point.

Subsplit - A two-way communications scheme for coaxial cable using the frequency range from 5 to 30 MHz for upstream transmission and 54 to 260 MHz for downstream transmission.

TDM (Time Division Multiplexing) - Division of the transmission time through a given medium into several intervals, each of which is used for a separate channel.

Terminal - An input/output device capable of transmitting entries to and obtaining output from the system of which it is a part.

Traffic - A measure of the usage of a communication channel. One unit for the measurement of traffic intensity is the Erlang which is the average number of simultaneous messages. More specifically, it is the total channel usage during an interval of time divided by the time interval, where all times are given in the same units, e.g., message-minutes per minute.

UHF - Ultra High Frequency. The frequency range from 300 to 3000 MHz.

Upstream Transmission - Transmission of signals from the subscriber to the headend in a cable television system.

VHF - Very High Frequency. The frequency range from 30 to 300 MHz.